BBC

RELATIVITY ON TRIAL
Will it change the way we understand our universe? *p58*

ASIA EDITION

Vol. 8 Issue 2

Knowledge

SCIENCE • HISTORY • NATURE • FOR THE CURIOUS MIND

INCORPORATING BBC SCIENCE WORLD

2015: THE BEST EVER YEAR FOR SCIENCE?

From rivers on Mars to designer humans, the breakthroughs that changed the way we see the world *p26*

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WILL ARTIFICIAL INTELLIGENCE FREE US FROM 9 TO 5? *p41*

THE AMATUERS TOYING WITH LIFE'S CODE *p74*

CAN DOGS REALLY DETECT CANCERS? *p88*

BBC Knowledge

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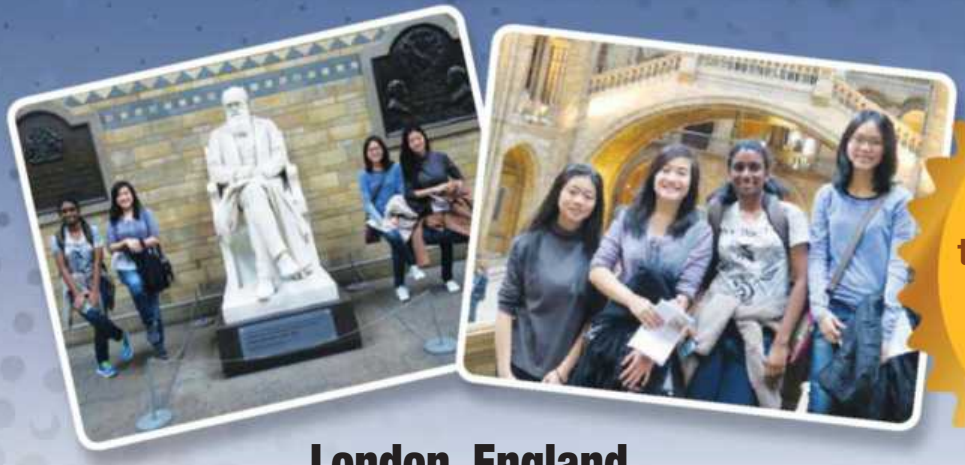

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On the cover

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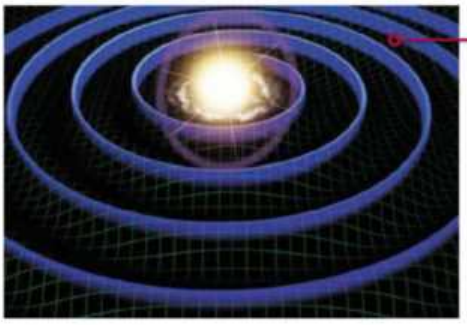

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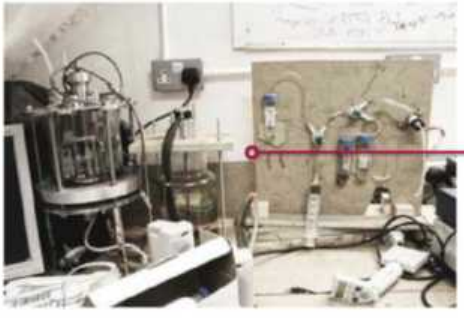

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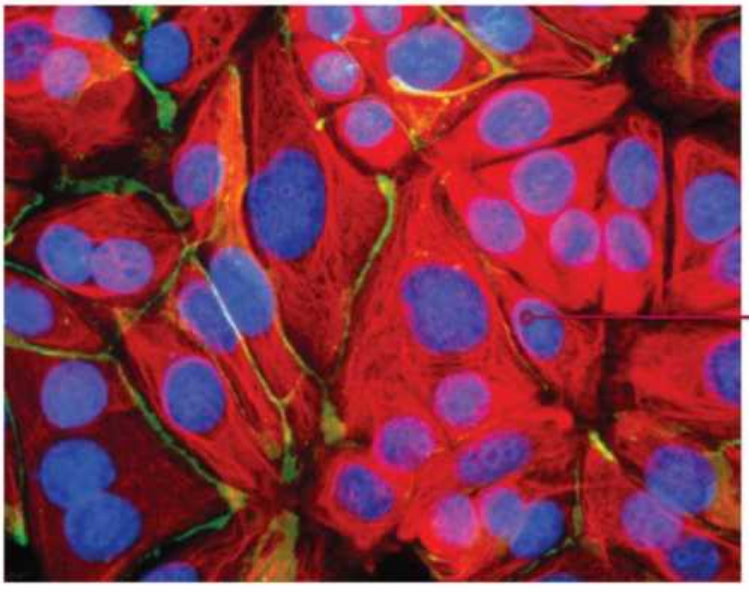

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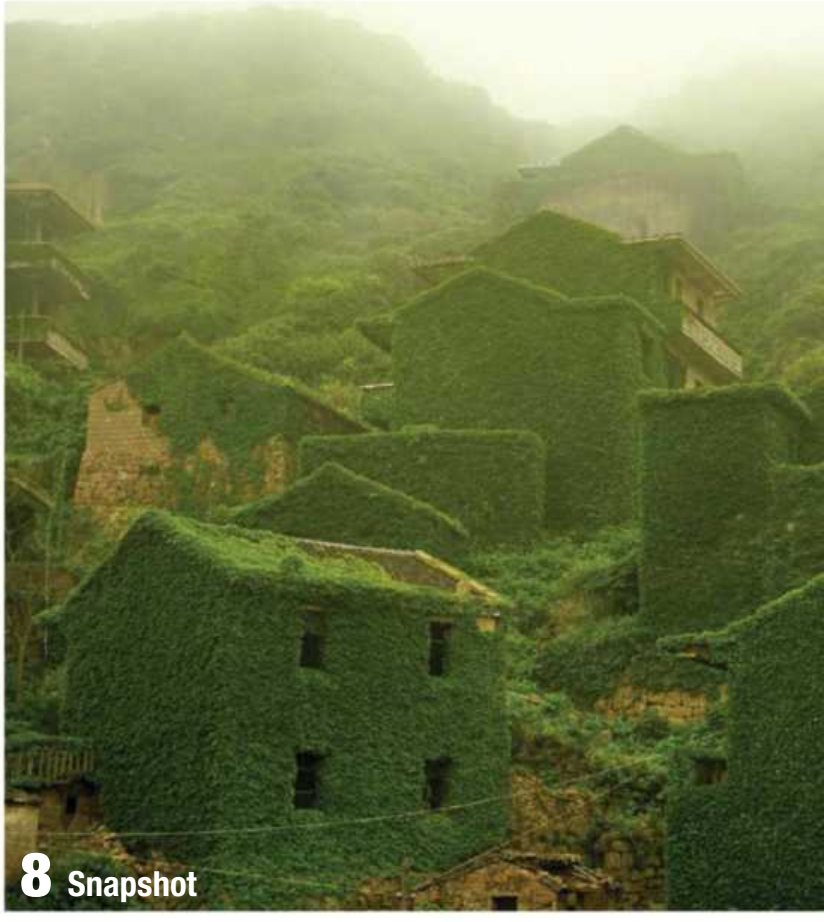

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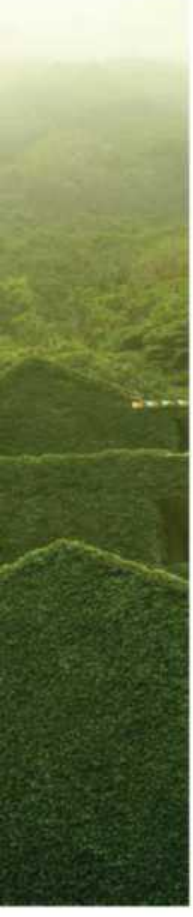

Welcome

✉ **Send us your letters**
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TOWARDS 2016 WITH HOPE

As we embark on another new year, it always pays to look back and take stock of the year that just zoomed by and how we got to 2016. For our cover story this issue, we look at 2015 and what a year it was for science! It seems that in recent years, the scientific community has been making large leaps in discoveries and developments.

2015 also happens to be 100 years since Albert Einstein explained to the world that the laws of physics act in the same way everywhere and that the speed of light is constant and since everything is moving relative to everything else, different viewers see the same event differently, and his all important Theory of Relativity was born, helping us shape our understanding of the universe.

On the medical front, resistance to antibiotics is a big worry and there hasn't been any new ones developed for decades. But in 2015 we had two, a variant of the existing isoniazid antibiotic that is used to target antibiotic-resistant tuberculosis and teixobactin, which attacks a part of the bacterial cell that is less able to mutate and produce resistance, extending its effectiveness. Let's hope that discoveries in 2016 will be able to top those in 2015.

Ben Poon
ben@regentmedia.sg

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✉ We welcome your letters, while reserving the right to edit them for length and clarity. By sending us your letter you permit us to publish it in the magazine and/or on our website. We regret that we cannot always reply personally to letters.

Experts in this issue...

JV Chamary

JV has a PhD in evolutionary genetics, making him the perfect chap to investigate the science amateurs who are meddling with DNA. Find out what he discovered on p74.

Marcus Chown

Einstein's General Theory of Relativity marks its 100th birthday this month. On p58, astronomer and cosmologist Marcus investigates the theories that may unravel it.

Helen Scales

Helen is a marine biologist, writer and broadcaster. On p36, she reports on the lionfish that are decimating Caribbean reefs and uncovers an unusual control method…

Kevin Surace

Kevin is the CEO of Appvance. At one of his TED talks, he painted a picture of a world in which no-one has to work. Is it too good to be true? We chat to him on p41.

✉ SEND US YOUR LETTERS

Has something you've read in BBC Knowledge Magazine intrigued or excited you? Write in and share it with us. We'd love to hear from you and we'll publish a selection of your comments in forthcoming issues.

Email us at:

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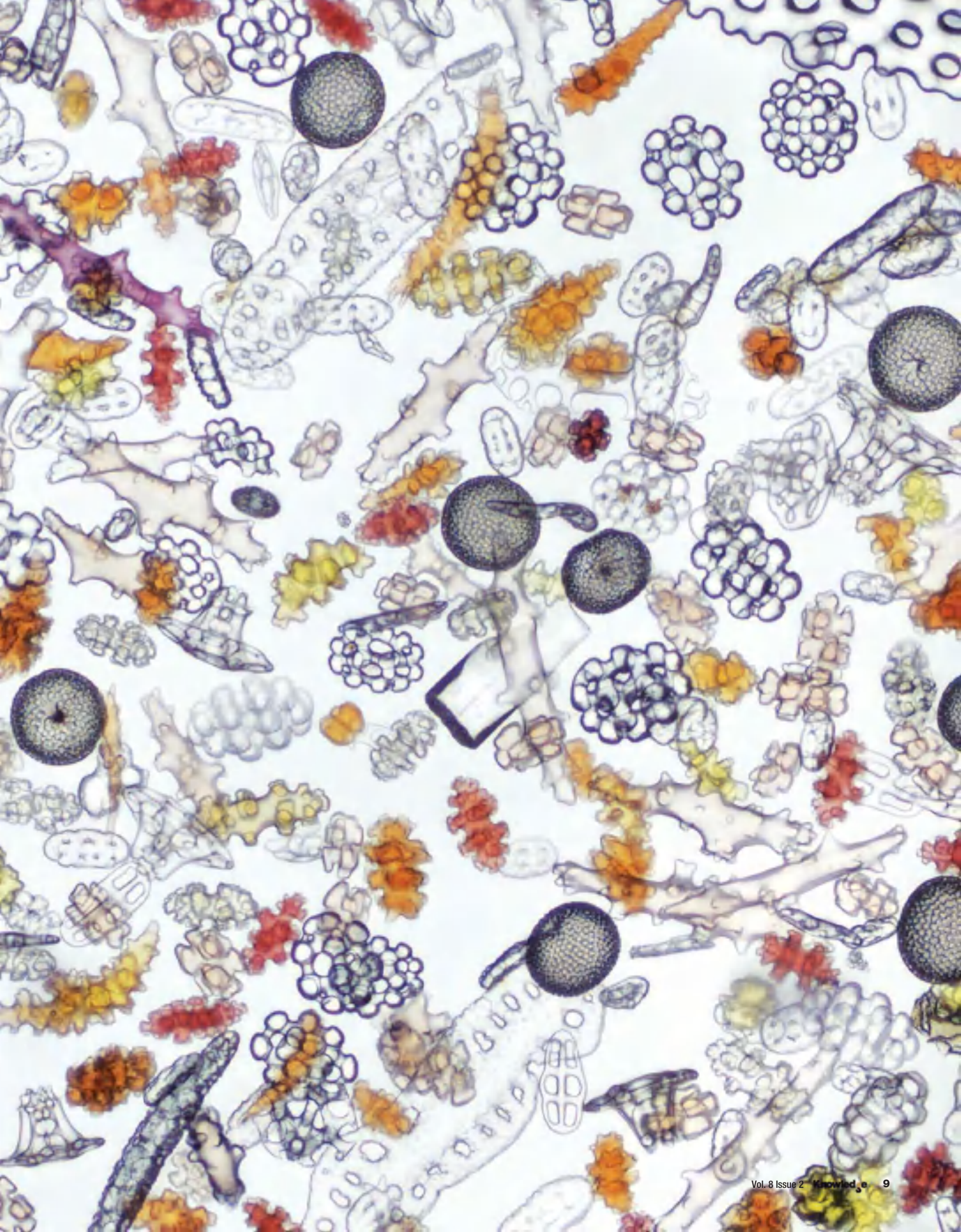
Snapshot

Sandy sweeties

There are catacombs hidden under Paris that contain the skeletons of the deceased. While these tombs seem a world away from a tropical coastline, the two locations are more similar than you might think. On the beach, the fine, white sand between your toes is made up of the remains of tiny invertebrates. But when viewed through a microscope, the beauty of the sand is brought to life. What looks like colourful pick-and-mix sweets are actually 'spicules'. These defensive calcium-based structures protect the soft bodies of marine organisms such as Gorgonian corals, sponges and sea cucumbers. This image was taken by award-winning wildlife photographer David Maitland.

PHOTO: DAVID MAITLAND/RPS/REX

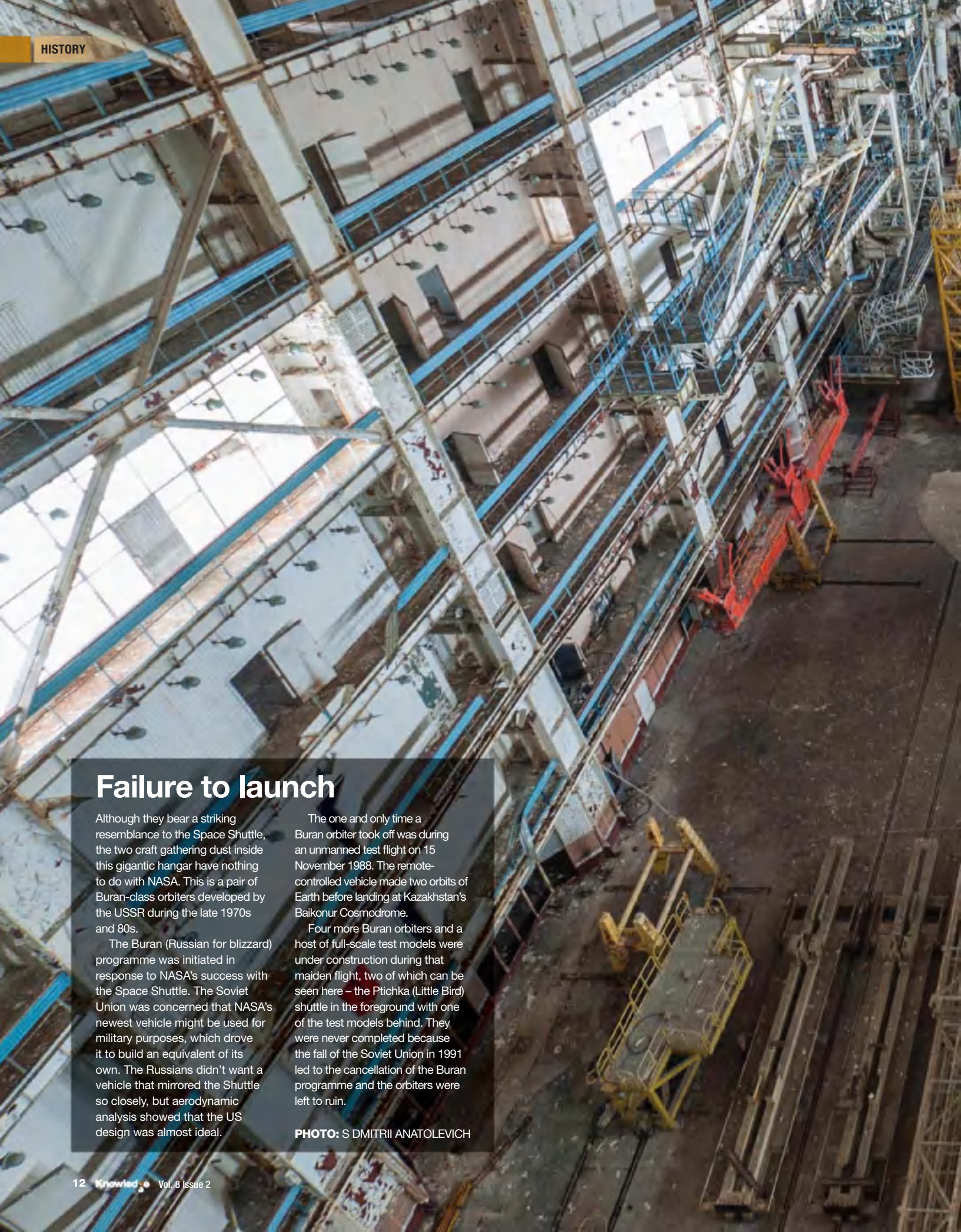


Greenhouses

The buildings of Gouqi Island are slowly being consumed by a thick blanket of green. The island is located a few hours east of Hangzhou Bay in eastern China, and was once home to a thriving fishing community. But as the shipbuilding and tourism industries grew, the village became deserted. With nobody left to maintain them, the buildings were soon reclaimed by the natural world.

"These buildings are covered with Parthenocissus tricuspidata, a relative of the grape vine and Virginia creeper. It's native to China but is also widely cultivated as an ornamental climber for its red autumn foliage," explains Dr Alastair Culham, Curator of the University of Reading's herbarium. "The climber was probably already planted there to decorate the houses. It's equivalent to ivy in the UK, which will soon cover a building if left alone."

PHOTO: GETTY



Failure to launch

Although they bear a striking resemblance to the Space Shuttle, the two craft gathering dust inside this gigantic hangar have nothing to do with NASA. This is a pair of Buran-class orbiters developed by the USSR during the late 1970s and 80s.

The Buran (Russian for blizzard) programme was initiated in response to NASA's success with the Space Shuttle. The Soviet Union was concerned that NASA's newest vehicle might be used for military purposes, which drove it to build an equivalent of its own. The Russians didn't want a vehicle that mirrored the Shuttle so closely, but aerodynamic analysis showed that the US design was almost ideal.

The one and only time a Buran orbiter took off was during an unmanned test flight on 15 November 1988. The remote-controlled vehicle made two orbits of Earth before landing at Kazakhstan's Baikonur Cosmodrome.

Four more Buran orbiters and a host of full-scale test models were under construction during that maiden flight, two of which can be seen here – the Ptichka (Little Bird) shuttle in the foreground with one of the test models behind. They were never completed because the fall of the Soviet Union in 1991 led to the cancellation of the Buran programme and the orbiters were left to ruin.

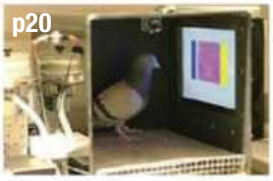
PHOTO: S DMITRII ANATOLEVICH

Update

THE LATEST INTELLIGENCE

LIGHT OUT OF DARKNESS
Black hole is spotted emitting a bright flare of X-ray light

TYPHOON WARNING
When the flood waters are rising, we can now call on NOAH for help



PIGEON POWER
How these urban birds could help in the battle against cancer

THE BIG STORY

WORLD'S MOST EXTENSIVE FACE TRANSPLANT

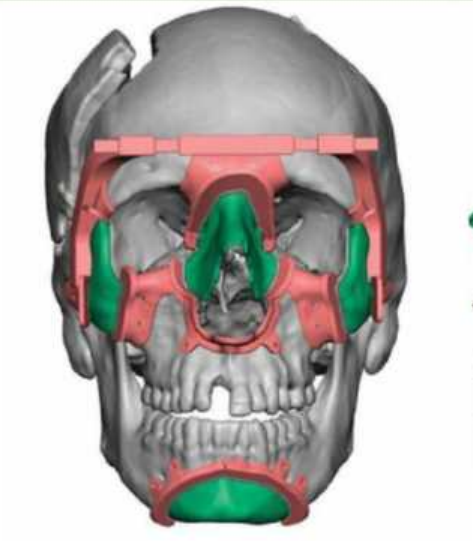
Plastic surgeons in the USA have successfully completed the most complicated face transplant to date

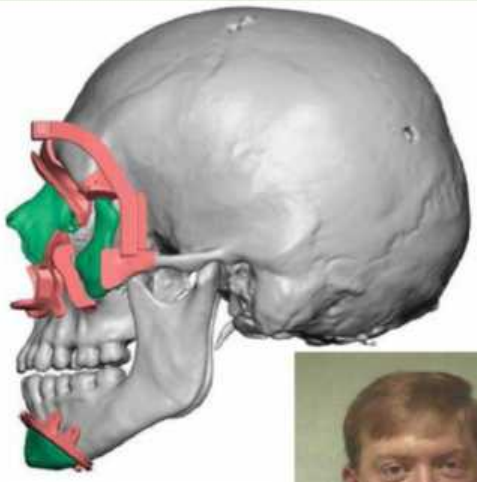
A team of surgeons in New York have successfully transplanted the scalp, forehead, face, ears and eyelids of a donor – as well as muscles, nerves and blood vessels – onto 41-year-old volunteer firefighter Patrick Hardison.

Hardison was badly injured when a burning home collapsed on him. He lost his ears and all of his hair, and was left with major facial scarring and disfigurement. Despite undergoing more than 70 operations, he was still unable to return to a normal life. In 2014 he was put on a waiting list for a donor that matched his skin tone, blood type and skeletal structure. A match

Patrick Hardison before and after the transplant

PHOTO: NYU LANGONE MEDICAL CENTER





Above: 3D scans showed the surgeons where to cut
Right: Hardison before the fire
Below: Hardison with Rodriguez after the face transplant

was eventually found when 26-year-old David Rodebaugh was declared brain dead after being involved in a cycling accident.

"When I met Patrick and heard his story, I knew that I had to do all that I could to help him, and every member of my team felt the same way," said Eduardo Rodriguez, who led the surgical team. "His surgery sets new standards in facial transplantation and will serve as an amazing learning tool. I am particularly encouraged with the success we have achieved in transplanting David's eyelids and blinking mechanisms to Patrick. This is a major milestone, one that could lead to preserving vision in future patients."

During the face transplant Rodriguez removed the donor's face and scalp, including the outer skin, tissue, nerves and muscle, as the surgical team removed the skin on Hardison's face. Rodriguez then placed the donor face on Hardison and connected the blood vessels. In order to ensure the transplanted tissue was as precise a fit as possible, the team used CT scans and 3D computer modelling techniques to build custom 3D-printed cutting guides.

Signs of success were already apparent in the final hours of the operation: colour returned to Hardison's face, indicating that blood was circulating into the tissue. Hardison is now undergoing physical therapy to build his strength and stamina and to enhance his ability to speak. He will also have to take medication to prevent his body from rejecting the transplant.

"I am deeply grateful to my donor and his family," Hardison said. "I hope they see in me the goodness of their decision. I also want to thank Dr Rodriguez and his amazing team. They have given me more than a new face – they've given me a new life."

Timeline
A history of face transplant surgery

2005

Isabelle Dinoire (pictured) is mauled by her dog after an accidental sleeping pill overdose. She is the first person to receive a transplant of living nose and mouth tissue.

2008

American Connie Culp receives a near-full face transplant, including bone, muscle, skin, blood vessels and nerves, after being shot in the face by her husband.

2010

A team of 30 Spanish doctors carry out the first full face transplant on a man injured in a shooting accident.

2012

Turkish surgeon Omer Ozkan performs a full face transplant on 19-year-old Ugur Acar, who was badly burnt in a house fire as a baby.

GOOD MONTH/ BAD MONTH

It's been good for:

GYM BUNNIES

Looks like it's time to hit the treadmill. Older adults who take moderate exercise have thicker cortices, the outer layer of the brain that typically atrophies in cases of Alzheimer's disease, researchers at the University of Maryland have found.

COFFEE DRINKERS

Make mine an espresso. A study at Harvard University has found that drinking two or three cups of coffee a day may reduce the risk of Type 2 diabetes and cardiovascular and neurological diseases.

It's been bad for:

SHARKS

It seems that climate change is just as bad news for sharks as it is for humans. Increasing sea temperatures lead to the fish becoming hungrier, but increased levels of carbon dioxide in the water are interfering with their ability to locate food via scent, researchers at the University of Adelaide have found.

PHOBOS

NASA has found that the long shallow grooves that can be seen running along the surface of Mars' biggest moon are 'stretch marks'

PHOTO: NYU LANGONE MEDICAL CENTER X4, PRESS ASSOCIATION, ISTOCK, NASA

Up ate

1 MINUTE EXPERT
Molecular 'Death Clock'

That sounds nasty. What is it?
It is the name for the processes inside cells that generate genetic mutations at a constant rate. They were discovered by researchers at the Wellcome Trust Sanger Institute.

Tell me more.
Every cell in the human body contains a copy of the human genome. Over the course of a lifetime, cells acquire mutations in their genomes. Some of these occur in bursts thanks to external factors such as smoking or exposure to sunlight. However, researchers have now found two types of mutation that correlate with age, suggesting that they are constantly 'ticking away'.

Is that a bad thing?
Probably. The researchers think that these processes could be responsible for a large number of human cancers and may contribute to human ageing.

Are there any practical implications?
Thanks to its constant rate, the process could help cancer researchers to predict how quickly a cancer can grow or spread to other parts of the body.

Cells obtain mutations that may cause ageing

PHOTO: NASA/JPL-CALTECH, JOLYON TROSCIANKO, BREUER LAB/BROWN UNIVERSITY, GENOME RESEARCH LTD

Artist's impression of an X-ray flare being emitted from a black hole

SPACE

Black hole has dramatic flare

Despite being among the darkest objects in the Universe, black holes are still capable of producing some of the brightest events.

NASA's Swift and the Nuclear Spectroscopic Telescope Array (NuSTAR) space telescopes have successfully captured Markarian 335, a supermassive black hole located 324 million light-years away in the direction of the constellation Pegasus, spewing out a gigantic flare of bright, energetic X-ray light.

The finding suggests that supermassive black holes send out enormous beams of X-rays when their coronas, sources of extremely energetic particles that surround them, are ejected.

"This is the first time we have been able to link the launching of the corona to a flare," explained lead author Dr Dan Wilkins from Saint Mary's University in Canada. "This will help us understand how supermassive black holes power some of the brightest objects in the Universe."

In September 2014, Swift and NuSTAR recorded a huge flare jetting out of Markarian 335 for several days. Careful analysis showed the corona being ejected from the black hole and eventually collapsing. Exactly why this occurs is not understood.

"The nature of the energetic source of X-rays we call the corona is mysterious, but now with the ability to see dramatic changes like this we are getting clues about its size and structure," said NuSTAR's Fiona Harrison.

Could NOAH save the Philippines from flooding?

DAVID SHUKMAN
The science that matters

My first impression of being in a typhoon was that it felt like warm buckets of water were being chucked over me. It made British storms look amateur. I was soaked through in seconds.

I was in the Philippines, an island nation that lies in the path of a typhoon production line fed by the warm waters of the Pacific Ocean, in late October just as Typhoon Koppu hit. The producer and I struggled with umbrellas above the cameraman who was desperate to save his lens.

The winds were powerful enough to knock down trees but it was the sheer scale of the downpour that did most damage. A staggering metre of rain fell in a couple of days. Roads became rivers.

There were casualties, but the death toll, which could have run into the thousands as in previous typhoons, was kept to low double figures. Good forecasting was key. Satellite images had spotted the distinctive tight spiral of the storm. Computer models suggested a likely path. And word of the danger quickly spread on Facebook and Twitter. This gave people a chance to get ready. A generation ago, the technology did not exist to make this kind of early warning possible.

Roads became rivers during Typhoon Koppu

But it's one thing to raise the alarm, quite another to forecast exactly which areas will be hit. The typhoon that we reported on followed the predicted track. Yet it caused flooding where none had been expected because intense rain in the hills made its way downstream into the cities.

There is an effort to deal with this. A project called NOAH, backed by a host of international experts including Britain's Environment Agency, is using airborne Lidar (a form of remote-sensing technology) to generate detailed terrain maps to better understand future water flows.

It cannot come soon enough. At a local weather station, we found a pair of bedraggled forecasters. They had thought the storm was missing them, only for sudden flooding to wreck their instruments. They smiled at the irony and one told me: "Let's hope we can be in better shape for the next one."

DAVID SHUKMAN is the BBC's Science Editor. @davidshukmanbbc

WHO'S IN THE NEWS?
Opeyemi Enoch

Who's he?
A mathematics professor based at the Federal University of Oye-Ekiti in Nigeria who claims to have solved the Riemann Hypothesis.

Hang on. Riemann what?
It's a notoriously tricky mathematical problem that was proposed by German polymath Bernhard Reimann back in 1859. It involves the distribution of prime numbers, those only divisible by themselves and one.

Enoch claims to have the solution, though as he has yet to publish his proof not everyone is convinced he is correct.

Why is it so important?
The Riemann Hypothesis is one of the seven so-called Millennium Prize Problems set by the Clay Mathematics Institute in 2000. The problems are so fiendishly difficult that the institute decided to offer $1m to the first person to solve one of them.

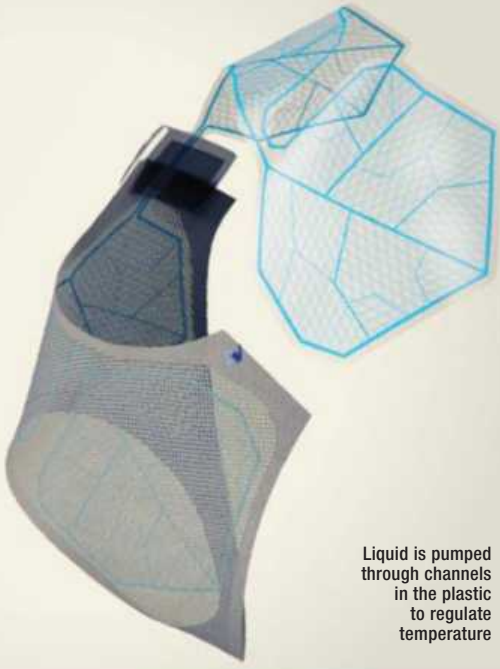
I fancy having a crack. Are there any still unsolved?
If Enoch has solved the Riemann Hypothesis, that leaves five of the original seven still unsolved: P versus NP, the Hodge Conjecture, the Yang-Mills Existence, the Navier-Stokes Existence and the Birch and Swinnerton-Dyer Conjecture. Good luck.

PHOTO: PRESS ASSOCIATION, ICMCS 2015

10 DISCOVERIES THAT WILL SHAPE THE FUTURE

10 Air-con coat

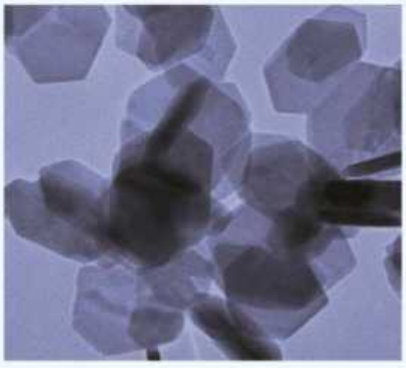
Imagine a jacket that could warm or cool you to a precise temperature. Thanks to a method of mass-producing plastic film containing tiny channels, developed at Finland's VTT Technical Research Centre, you may soon be wearing one. The film can be added to clothing, then hot or cold liquid can be pumped through the channels. The team calls the technology 'smart fabric', and the temperature can be selected with the aid of a smartphone. Certainly beats bundling yourself in woollies during the winter months.



Liquid is pumped through channels in the plastic to regulate temperature

9 Smartphone pollution sensor

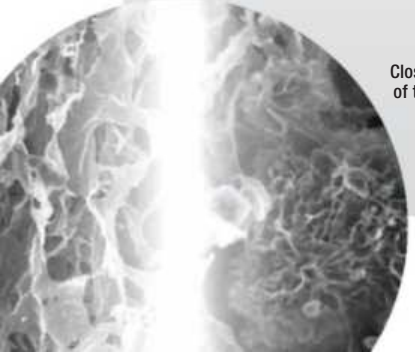
Worried about inhaling nitrogen dioxide from diesel engines? Your smartphone could one day help you avoid it, thanks to a new sensing method developed by scientists at Australia's RMIT University. The method uses flakes of tin disulphide, which absorb molecules of nitrogen dioxide. The flakes are a few atoms across, and could be placed into a sensor small enough to hold in your hand or build into a phone. The team says their method is cheaper and more sensitive than existing detectors.



The tin disulphide flakes are sensitive to nitrogen dioxide

8 The ultimate battery

Want an electric car you can drive from London to Edinburgh on a single charge? Well, it's coming. At the University of Cambridge, scientists are aiming to build a so-called 'lithium-air' battery capable of storing 10 times more energy than a lithium-ion battery and costing only one-fifth as much. Currently, the prototype has a graphene electrode that works in pure oxygen – a version that works in air is a decade away.



Close-up image of the battery's structure

7 LEDs from food waste

Energy-saving light bulbs and TVs contain LEDs, which produce light from crystals called 'quantum dots'. At the University of Utah, scientists have learned how to make quantum dots from food waste – specifically, chemicals in discarded pieces of bread, tortilla and soft drinks. The goal is to produce more environmentally friendly LEDs than those made from cadmium selenide, which is toxic when it breaks down.

6 Self-healing concrete

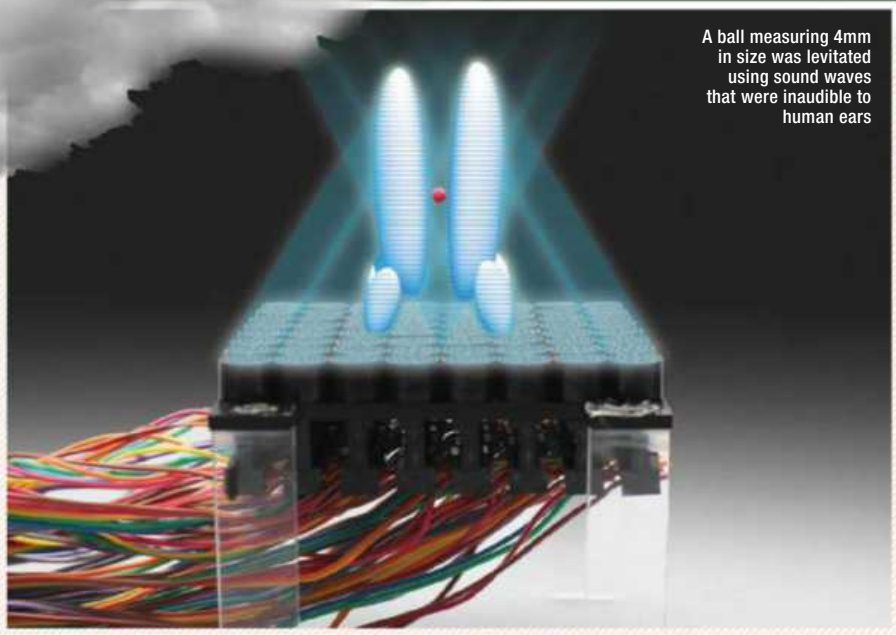
A team at Cardiff University is testing types of self-healing concrete, which could reduce the annual US$58bn bill for repairing roads and buildings. When embedded sensors detect damage, they trigger a mechanism to repair it. Either shape-shifting materials move within the concrete, or bacteria produces calcium carbonate to fill the cracks.

Test walls have been built from the self-healing concrete

PHOTO: VTT RESEARCH, BRISTOL UNIVERSITY, DONGHUA UNIVERSITY, CARDIFF UNIVERSITY, TAO LIU/GABRIELLA BOCCHETTI/CLARE P GREY

5 Climate-saving bacteria

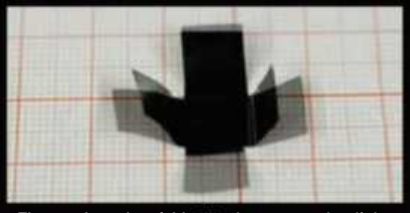
The enzymes produced by the bacterium Thiomicrospira crunogena could help in the fight against climate change. The bacterium lives at the bottom of the sea and its enzymes convert carbon dioxide to bicarbonate. They can operate at the high temperatures and pressures found in industry.



A ball measuring 4mm in size was levitated using sound waves that were inaudible to human ears

4 Self-folding paper

Tiny robots and artificial muscles are just two potential applications of this self-folding paper made from graphene oxide. It folds in response to heat or light, allowing it to 'walk' and can support objects up to five times its weight.



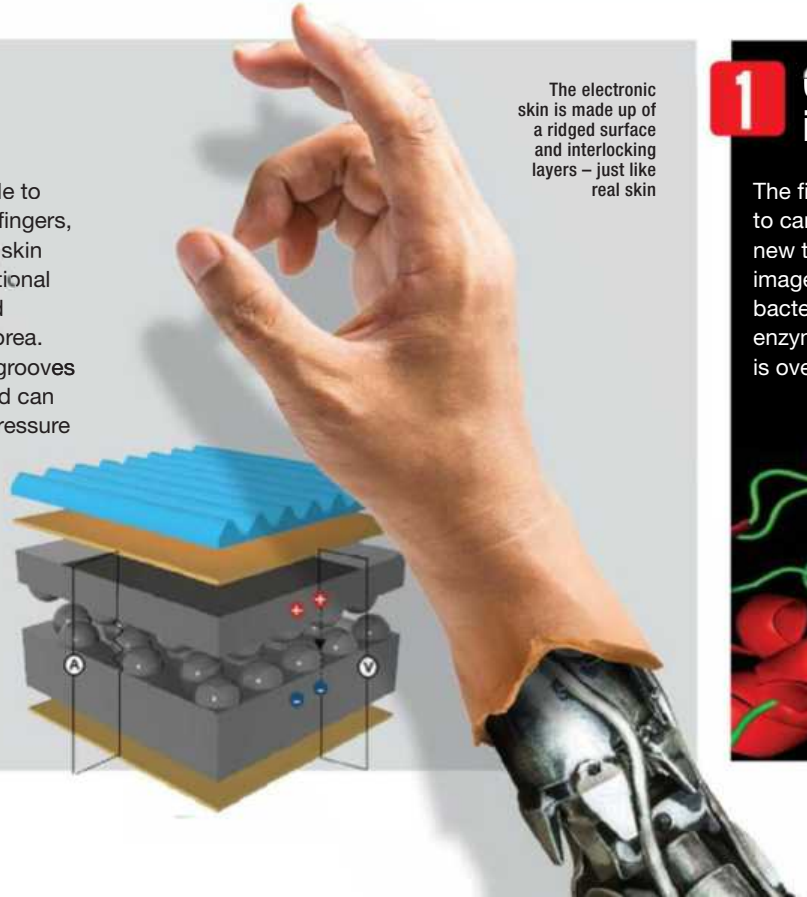
The graphene box folds up when exposed to light

3 Sonic tractor beam

The tractor beam in Star Trek wasn't so far-fetched after all. Bristol and Sussex universities have built one that uses sound to move small objects without physically touching them. It could be used to assemble miniature products on a floating production line or to guide drug-delivery capsules through your body. It works by surrounding objects with high-intensity sound from an array of 64 tiny loudspeakers. The loudspeakers generate acoustic force fields, which are manipulated to pick up an object and then move, hold or rotate it.

2 Artificial skin

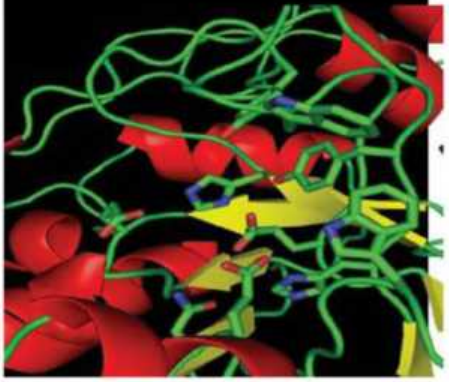
Robots will soon be able to feel sensations in their fingers, thanks to an electronic skin developed at Ulsan National Institute of Science and Technology in South Korea. The e-skin mimics the grooves on human fingertips and can detect both heat and pressure simultaneously. It's sensitive enough to detect the weight of a single human hair and, worn on a human wrist, the tiny change in temperature caused by blood vessels dilating.



The electronic skin is made up of a ridged surface and interlocking layers – just like real skin

1 Cancer protein in 3D

The first 3D image of a protein linked to cancer could help pave the way for new treatments for the disease. The image shows an enzyme known as a bacterial heparanaze. Humans have an enzyme with the same function, which is overexpressed in cancers.



MEDICINE

Pigeons can spot cancer on medical images 'as well as humans'

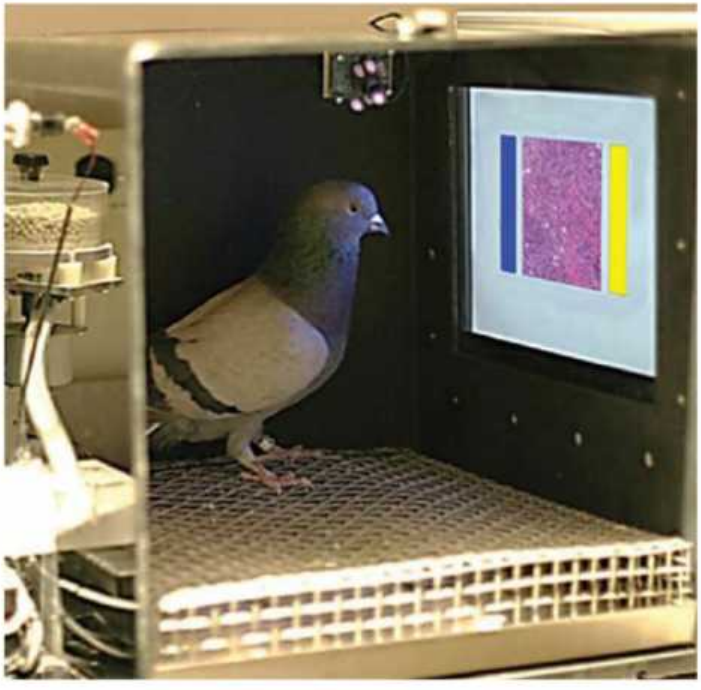
It seems pigeons may not be so bird-brained after all. A team at the University of California, Davis has trained the birds to pick out cancerous breast tissue on mammograms.

After two weeks of training, using food as motivation, the pigeons were able to correctly identify cancerous tissue 85 per cent of the time. This is a level of accuracy similar to that of human radiologists.

"Research over the past 50 years has shown that pigeons can distinguish identities and emotional expressions on human faces, letters of the alphabet, misshapen pharmaceutical capsules, and even paintings by Monet vs Picasso," said co-author Edward Wasserman. "Their visual memory is equally impressive, with a proven recall of more than 1,800 images."

Even after years of training, physicians can sometimes struggle to correctly interpret mammograms. The process is also time-consuming, labour-intensive and expensive. Though it's unlikely you will ever be booking an appointment with a pigeon GP, lead researcher Prof Richard Levenson believes that the common birds could play a part in further developments in imaging and display technologies.

"Pigeons' sensitivity to diagnostically salient features in medical images suggests that they can provide reliable feedback on many variables at play in the production, manipulation, and viewing of these diagnostically crucial tools, and can assist researchers and engineers as they continue to innovate," he said.



The pigeon will see you now…

EARTH

Water has been on Earth all along

Lava samples offered the teams pristine examples of the water present when Earth formed

The Earth is known as the Blue Planet for good reason: liquid water covers more than two-thirds of its surface. But exactly how it got there has always been a bit of a puzzle. The question at the heart of the mystery is: was water present when the planet formed 4.5 billion years ago or did it arrive later, perhaps carried here by comets and meteorites?

Now, researchers at the Universities of Glasgow and Hawaii have found evidence that suggests water has been on the Earth since its formation.

The team used an ion microprobe to analyse tiny amounts of water held within a collection of primitive rocks known to have formed deep within the Earth's mantle. Different Solar System bodies have distinct ratios of hydrogen to deuterium (heavy hydrogen) in their water, so by measuring this, the researchers were able to determine its origin.

"We found that the water had very little deuterium, which strongly suggests that it was not carried to the Earth after it had formed and cooled. Instead, water molecules were likely carried on the dust that existed in a disk around our Sun before the planets formed," said researcher Lydia Hallis.

"Over time, this water-rich dust was slowly drawn together to form our planet. Even though a good deal of water would have been lost at the surface through evaporation in the heat of the formation process, enough survived to form the world's water," she added.

THEY DID WHAT?

Scientists eavesdrop on crows' conversations

What did they do?
Researchers from the Universities of Bath and St Andrews fitted spy tags to a group of 41 crows in the remote island of New Caledonia in the South Pacific and recorded their interactions. They then placed a log full of wood-boring beetle grubs within easy reach of the crows and again observed their behaviour.

Why did they do that?
Crows are one of a handful animals capable of using tools. The team wanted to see how crows share knowledge and skills with one another.

What did they find?
When the crows were presented with a ready food source, like the beetle grubs, they congregated around it. This increased the spread of information between them. The researchers likened the effect to office workers gossiping around a water cooler or coffee machine.

"And I said to her that the boss is being an idiot"

ENGINEERING

Solved: how bats land upside down

Bats are famous for hanging upside down when sleeping or resting. But in order to get into this position they have to perform a mid-air flip that would put even the most agile trapeze artist to shame. Quite how they manage to do this has baffled scientists. However, biologists at Brown University think they finally have the answer.

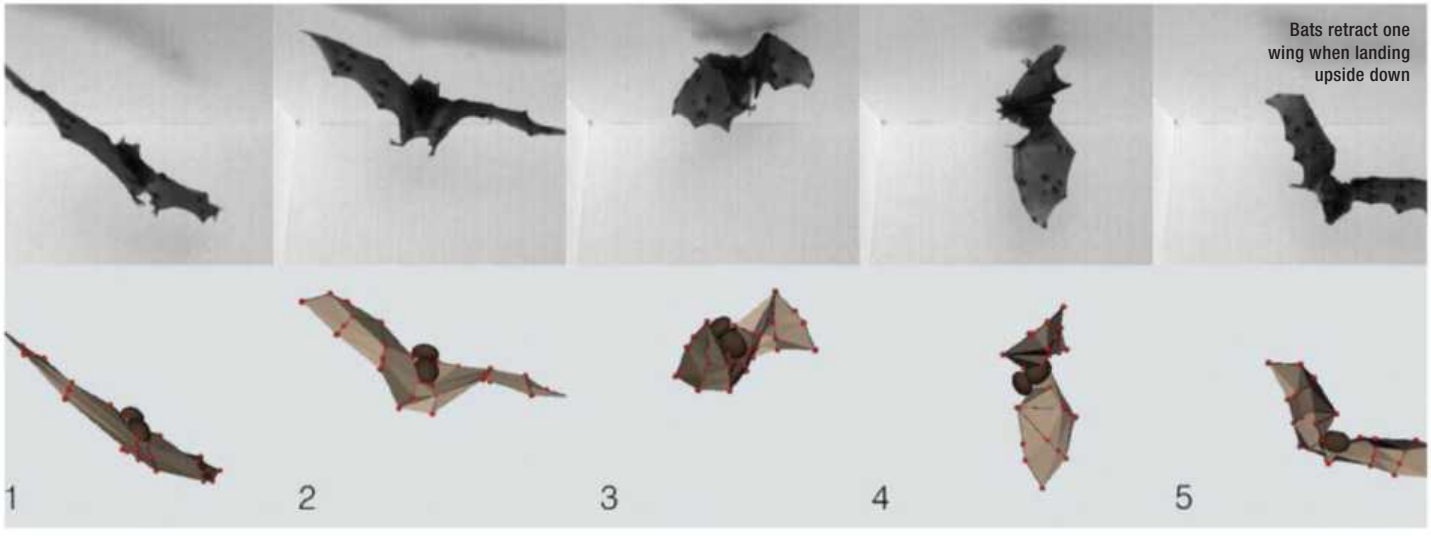
"Bats land in a unique way," said researcher Prof Sharon Swartz. "They have to go from flying with their heads forward to executing an acrobatic manoeuvre that puts them head down and feet up. No other flying animal lands the same way as bats do."

To investigate the intricate manoeuvre, the team rigged up a high-speed camera and recorded two species of bats, Seba's short-tailed bats and lesser dog-faced fruit bats, as they landed on a piece of mesh attached to the ceiling of an enclosure.

Bats have the heaviest wings compared to bodyweight of any flying animal, and it turns out this extra weight helps them perform their aerobatic moves. As they approach to land, they slightly retract one wing while flapping the other at full extension. This results in the animals rotating in the air in much the same way as Olympic high divers.

As well as answering an age-old question, the finding may be useful in the development of man-made flying machines.

"From an engineering perspective, there's a lot of interest in drones and flying microvehicles," co-author Prof Kenny Breuer explained. "Manoeuvring or directing those robotic vehicles is a challenge. The idea here is that using redistribution of mass is not a bad approach to take."



Bats retract one wing when landing upside down

NANOTECHNOLOGY

‘Nano-subs’ may soon be swimming in your bloodstream

Remember the mini submarine Dennis Quaid used to cruise around the human circulatory system in classic 80s sci-fi movie Innerspace? Well, researchers at Rice University have made the next best thing: a 244-atom nano-submarine that could be used to deliver medicines inside the body.

The subs are powered by motors that operate in a similar fashion to a bacteria’s flagellum – the tail-like filament that allows microbes to swim through fluids.

When excited by ultraviolet light, the bond that holds the rotor to the body changes state allowing it to rotate a quarter turn. Then as it returns to its resting state, it jumps again rotating another quarter turn. This process continues so long as the light is on.

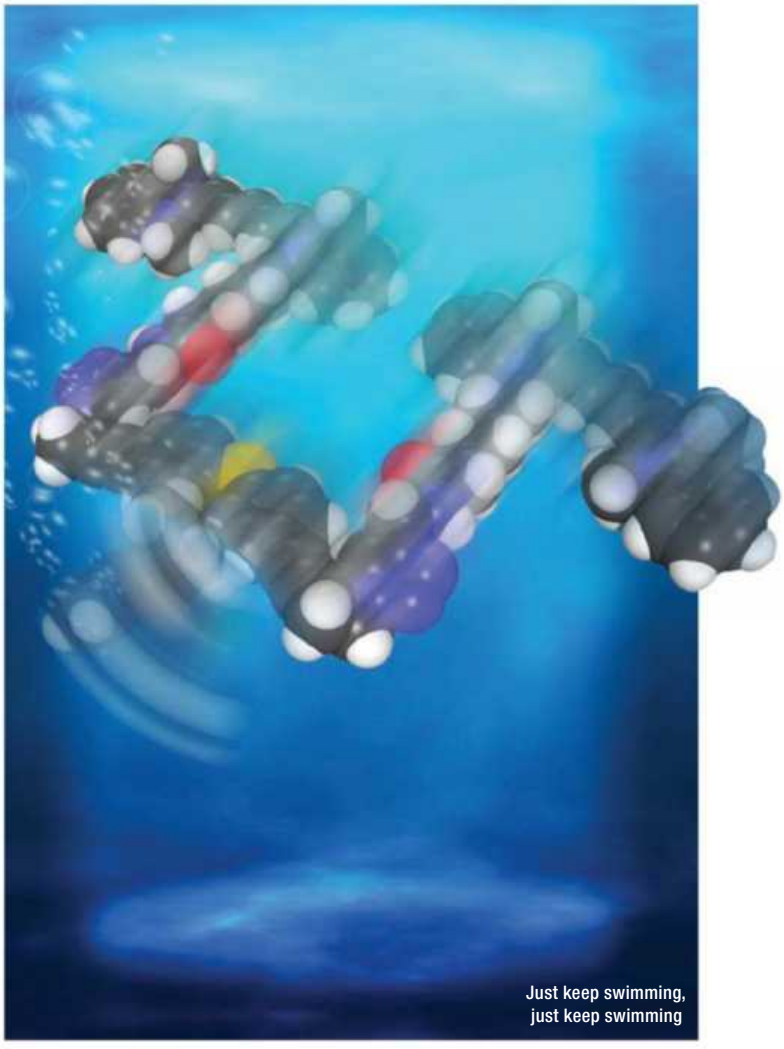
The motors run at more than 1,000,000rpm and can reach speeds of just under 2.5cm per second. This may not sound particularly nippy, but in molecular terms it’s breakneck speed.

The subs can’t be steered yet, but the study proves the molecular motors are powerful enough to drive subs through solutions of moving molecules of about the same size.

“This is akin to a person walking across a basketball court with 1,000 people throwing basketballs at him,” said lead researcher James Tour.

With further refinement, the researchers hope the nanosubs will be able to carry cargoes for medical and other purposes.

“There’s a path forward,” co-author Victor García-López explained. “This is the first step, and we’ve proven the concept. Now we need to explore opportunities and potential applications.”



Just keep swimming, just keep swimming

PHOTO: LOIC SAMUEL/RICE UNIVERSITY

PATENTLY OBVIOUS with James Lloyd

Inventions and discoveries that will change the world

Tech for tots

You might not think that all that cooing baby talk has much of an effect, but studies show that speaking to your infant has a crucial impact on their development. The Starling is a star-shaped device that clips to your baby’s clothes and keeps track of the number of words you speak to them, lighting up green when you’ve reached your daily target. The companion app will even suggest activities if you’re at a loss for words.

Patent pending

Raising the bra

What do geckos and women’s underwear have in common? A lot more than you might think. Geckos can run across ceilings thanks to the microscopic structure of the their toes. Now, US engineer Anthony Roy has created a silicone-based material called GeckTeck that uses the same principle to attach a strapless bra to the skin, providing a comfortable adhesive that can be reused thousands of time.

When fixed to the band of a bra, it allows the wearer to glam up without having to spend the whole night fiddling with their outfit. Now, where’s that strapless crop top?

Patent pending

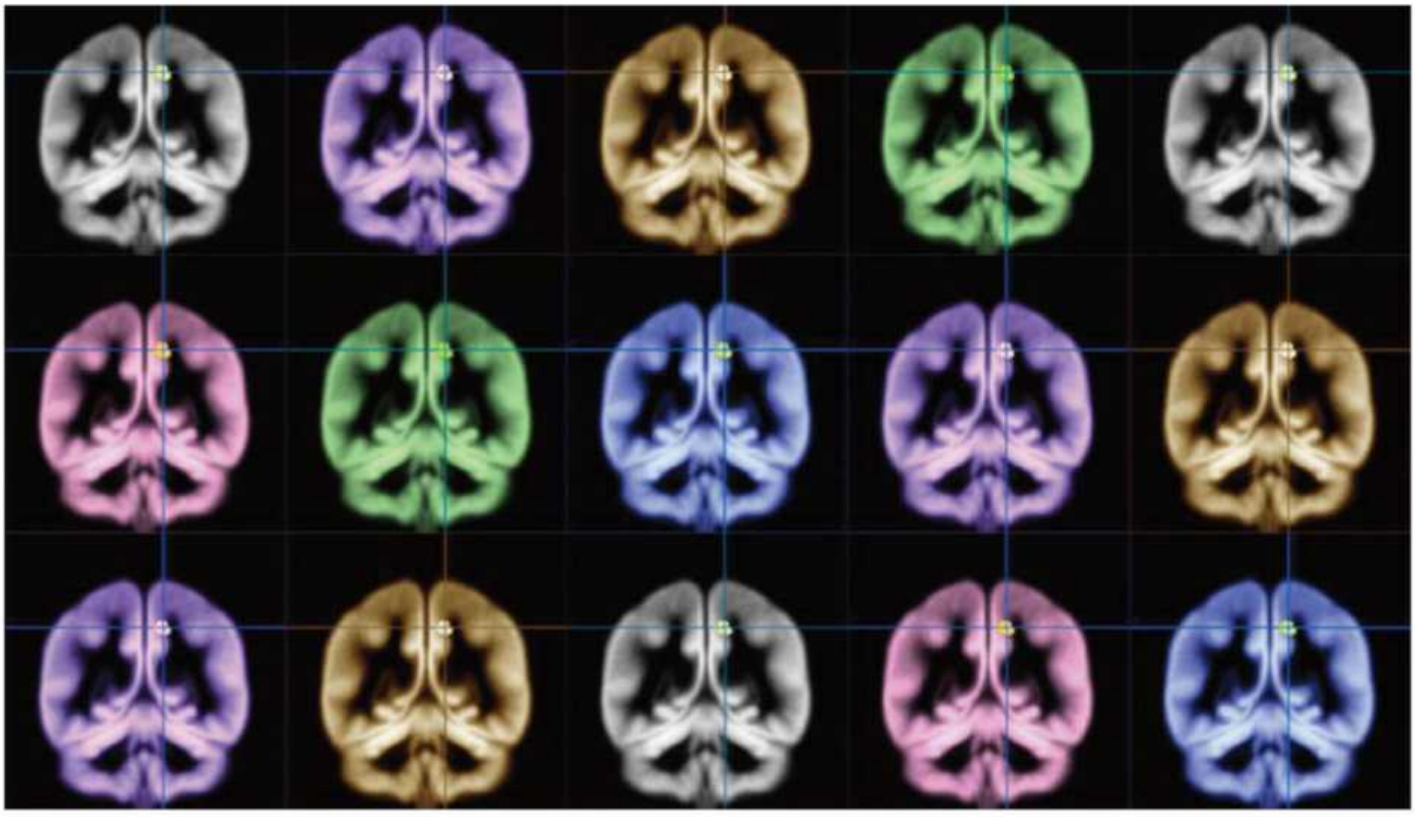
Dunk-proof phones

When the best way of saving a wet phone involves plunging it in a bowl of rice, you know that it’s time for change. Apple is patenting a system that detects water inside your phone and squirts it out of the speakers. The technology works by varying the electrical charge of electrodes inside the speaker cavity – this alters their water-repelling properties and moves the liquid towards the exit. Maybe the technology will find its way into the iPhone 7, in which case we’ll be able to save the rice for that tikka masala.

Patent application number: US 20150326959

NEUROSCIENCE

Root of happiness found in brain



MRI scans of the brain have helped scientists find the source of happiness

If you have a tendency to look on the bright side of life, chances are you've got a pretty active precuneus.

A team at Kyoto University scanned the brains of volunteers using MRI and then asked them a series of questions such as how happy they are generally, how intensely they feel emotions, and how satisfied they are with their lives.

It turned out that those who scored higher on the happiness survey had more grey matter mass in their precuneus, an area of the brain situated between the two hemispheres.

"Over history, many eminent scholars like Aristotle have contemplated what happiness is," said lead author Wataru Sato. "I'm very happy that we now know more about what it means to be happy."

Now, Sato is looking into whether or not we can train ourselves to be happy. "Several studies have shown that meditation increases grey matter mass in the precuneus. This new insight on where happiness happens in the brain will be useful for developing happiness programs based on scientific research," said Sato.

SPACE

First photo of a planet in the making

It's like an ultrasound scan for a nascent planet: researchers at the University of Arizona have captured the first ever photo of a planet as it is forming.

The team noticed the nascent planet when observing LkCa15, a young star surrounded by a 'protoplanetary disk' located 450 light-years from Earth.

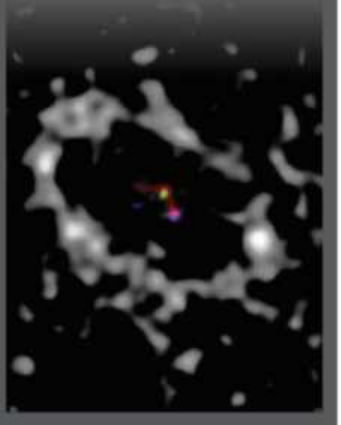
Protoplanetary disks form around young stars using the debris left over from the star's formation. It is suspected that planets then form inside the disk as the dust groups together.

"This is the first time that we've imaged a planet that we can say is still forming," said researcher Steph Sallum.

Of the roughly 2,000 exoplanets – planets that orbit stars other than the Sun – observed so far, only around 10 have been imaged.

The photo of the planet was taken using infrared imaging technology on Arizona's Large Binocular Telescope (LBT) and then confirmed with observations from the Magellan Telescope located in Chile.

"Results like this have only been made possible with the application of a lot of very advanced new technology to the business of imaging the stars, and it's really great to see them yielding such impressive results," said co-author Prof Peter Tuthill.



The baby planet is about 450 light-years away

PHOTO: KYOTO UNIVERSITY, UNIVERSITY OF ARIZONA

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A simple compass reveals a whole new world

You'd have thought I'd know my own home, but I discovered this week that there's far more to it than I'd appreciated. I bought myself a nice, sensitive navigational compass, sadly not one with a shiny brass case and engravings of ships, but still a compass in the original style with a quivering needle and a bold arrow for north. I spent a while doing pirouettes and being impressed that the needle could keep up, then I put it down next to a metal ruler on my desk. The needle whizzed round and pointed at the ruler. It had never occurred to me that the ruler might have its own magnetic field. The compass clearly had far more than navigation to offer. Twenty minutes of wandering round my flat, watching as the needle mapped out what I couldn't see, changed my view of where I live.

When you think about it, it's pretty cool that compasses work at all. The Earth has its own magnetic field that pokes out of the magnetic North Pole (which isn't in quite the same place as the geographic North Pole) and reconnects with the planet at the South Pole. It's a fairly weedy magnetic field – even a standard fridge magnet is 100 times stronger. But it's always there, wherever you are. If you put two bar magnets next to each other, their north poles will fly apart and they'll spin around until their north and south ends touch. And if you put a bar magnet on the surface of the Earth, it will also spin to align itself if it's free to move. That's why the needle on my compass is so delicate – there's very little friction or inertia to stop it moving. Every bar magnet will feel the tug of the planet - this needle is only special because it can respond very quickly.

Mostly, the magnetic field pushes the needle to point north. But my steel kitchen knives all re-shape their local magnetic field, adding a loopy pattern on top of the Earth's magnetic background. The needle spins around each knife, showing that something magnetised it in the past and it's never lost that magnetism. The pattern from the iron saucepans is all over the place, and it's the same for my tablet computer, battery-powered clocks, plug sockets, the television and my keys. A bit more investigation shows that the metal ruler actually has quite a complicated magnetic field – it changes direction every few centimetres. But magnetic field strength drops off very quickly with distance, so each object only adds small twirls and twists to the overall pattern. My neodymium magnets in the corner are the magnetic giants in the room, their influence extending out for 30cm or so from the bookcase.

There are magnetic patterns all around your house, and you just need a compass to find them

"Now, when I look around my flat, I imagine delicate magnetic field lines running through it, and through me"

And this is just the fixed magnetic patterns. The alternating current running through the wires in the walls is generating its own magnetic pattern, but since it's changing direction 50 times each second, my compass can't move fast enough to show it. The push of a changing current like that on a permanent magnet can make the magnet spin as it tries to keep up – that's all an electric motor is.

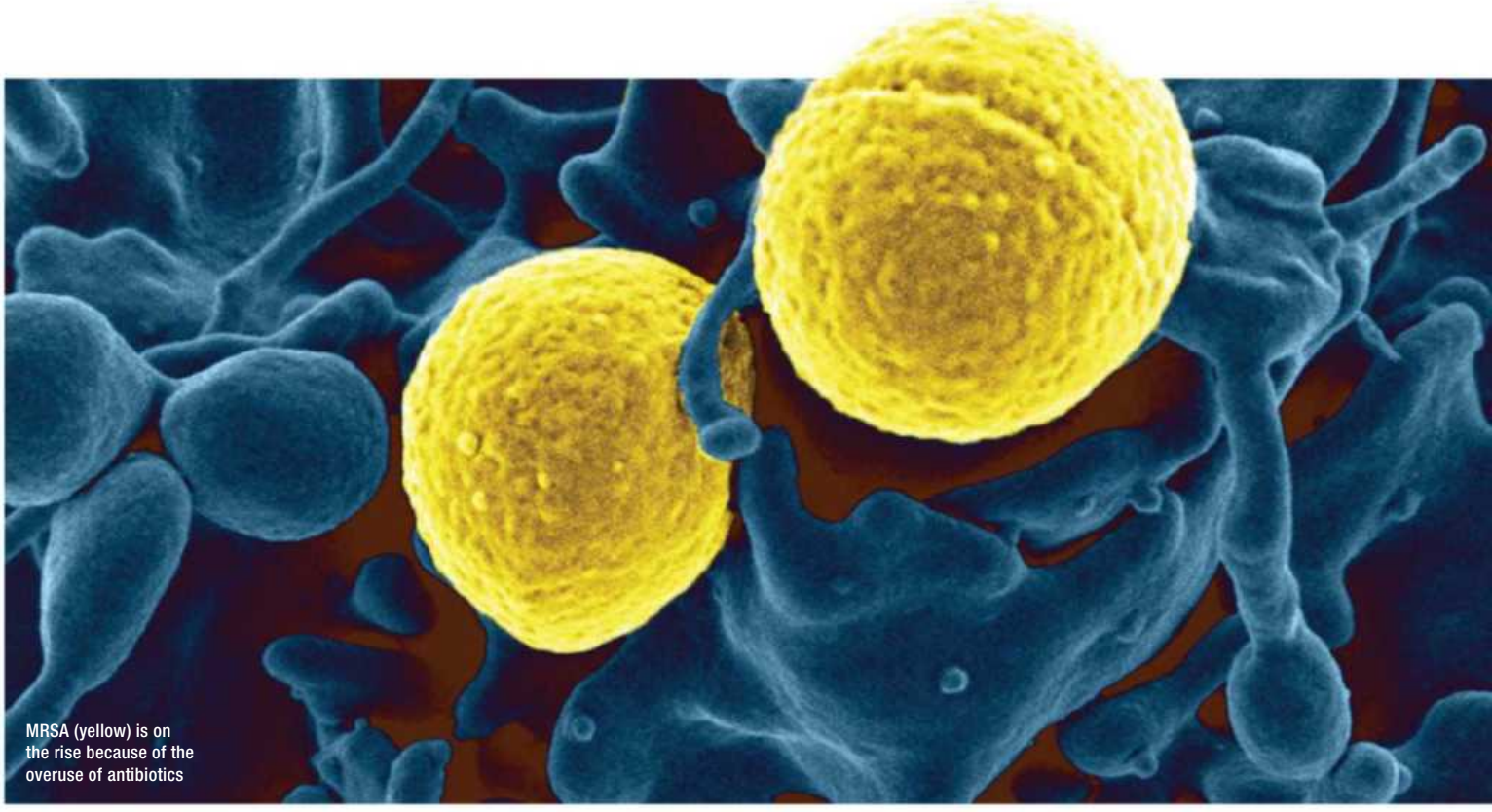
So now, when I look around my flat, I imagine delicate magnetic field lines running through it, and through me. Their straight flow is being sculpted into whorls by temporarily magnetised iron and by electric components and circuits. None of it is harmful to us. But the most amazing thing of all is the comparison between this minuscule compass needle, and the vast planetary-scale magnet that it detects. It's such a simple way of mapping out our magnetic world!

DR HELEN CZERSKI is a physicist, oceanographer and BBC science presenter whose most recent series was *Super Senses*

ILLUSTRATOR: ANDREW LYONS

2015: THE BEST EVER YEAR FOR SCIENCE?

2015 has been an incredible year for Science. We've explored Pluto, revolutionised medicine, found evidence of water on Mars and brought animals back from the brink of extinction. So will 2015 go down in the history books as a turning point? Brian Clegg looks back over some of the year's most impressive scientific achievements



MRSA (yellow) is on the rise because of the overuse of antibiotics

NEW ANTIBIOTIC IS DISCOVERED

As bacteria increasingly evolve to survive the attack of antibiotics, we could see modern medicine devastated. Overuse of antibiotics means that we are threatened by 'superbugs' like MRSA that can survive our armoury.

Until 2015, we hadn't developed a new antibiotic for decades. But two new substances are under test that could extend the fight against superbugs. One, being developed by drug company Novartis, is a variant of the existing isoniazid antibiotic that is used to target antibiotic-resistant tuberculosis. It works because it bypasses the mechanism used by a bacterium to develop resistance. But more dramatic is teixobactin, which was derived from 'wild' bacteria in soil and works in a different way to conventional antibiotics, attacking a part of the bacterial cell that is less able to mutate and produce resistance. "Uncultured bacteria make up approximately 99 per cent of all species in external environments, and are an untapped source of new antibiotics," said the researchers. If a drug is developed from teixobactin, it could be effective against bacteria like MRSA for decades to come.

WHY SHOULD I CARE? An increase in antibiotic resistance in bacteria is putting our lives at risk.

WHAT'S NEXT? Researchers are hunting for more antibiotics like teixobactin in the wild.

An iChip is used to house growing microorganisms for antibiotic research

PHOTO: GETTY, NASA, TODD MARSHALL ILLUSTRATOR: ANDY POTTS

THE YEAR IN BRIEF…

JAN

BIG FISH

In January, a fossil that had been sitting in a Glasgow museum since 1959 was identified as a previously unknown species of ichthyosaur, *Dearcmhara shawcrossi*. The marine reptile lived in Scottish waters 170 million years ago, and grew up to 4m long.

A NEW EARTH?

Exoplanet Kepler 438b was confirmed in January, and is thought to be the most Earth-like exoplanet yet discovered. Sadly, further studies have shown that it's too close to its parent star to ever be capable of hosting carbon-based life, due to high radiation levels.

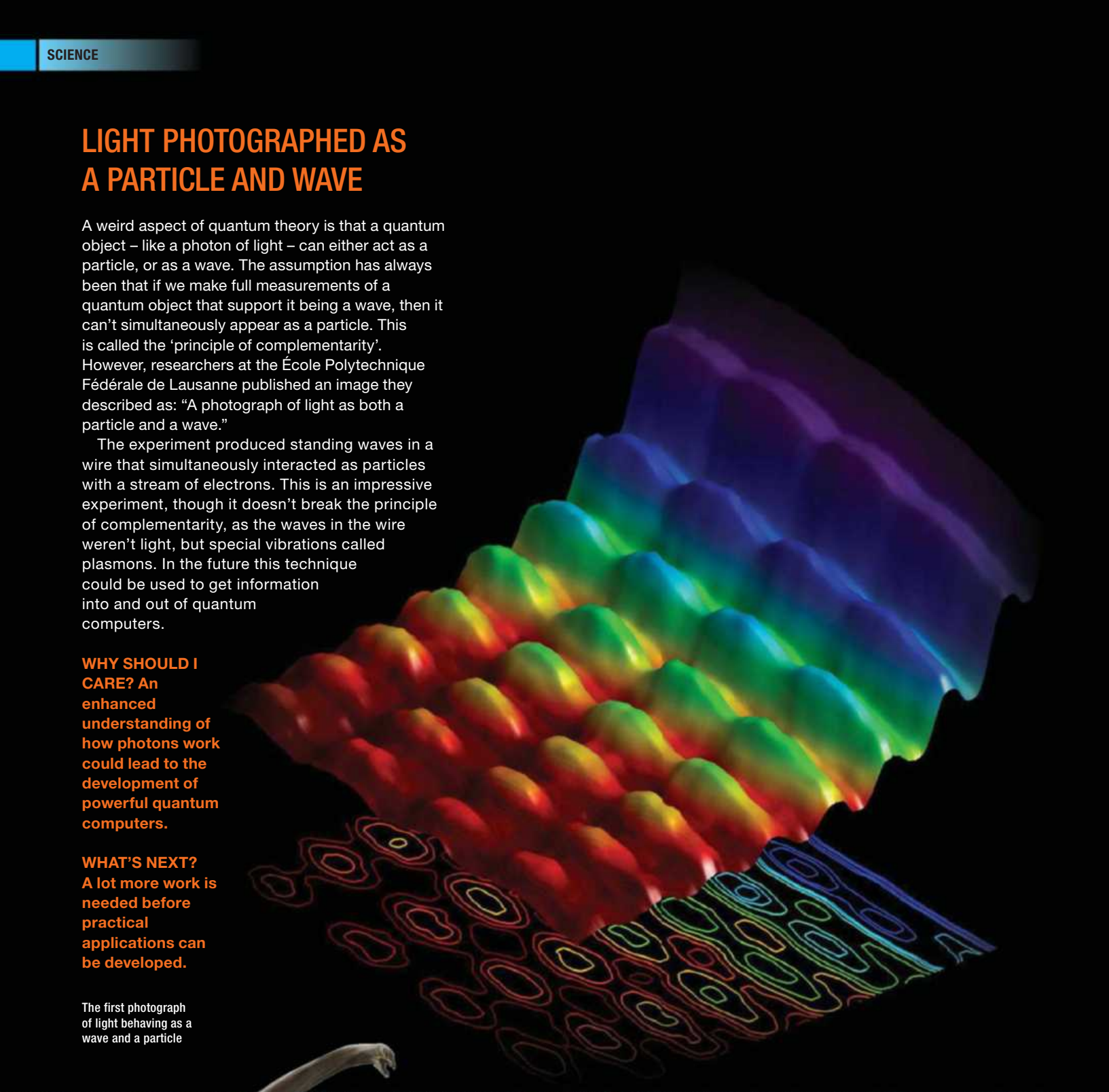
LIGHT PHOTOGRAPHED AS A PARTICLE AND WAVE

A weird aspect of quantum theory is that a quantum object – like a photon of light – can either act as a particle, or as a wave. The assumption has always been that if we make full measurements of a quantum object that support it being a wave, then it can't simultaneously appear as a particle. This is called the 'principle of complementarity'. However, researchers at the École Polytechnique Fédérale de Lausanne published an image they described as: "A photograph of light as both a particle and a wave."

The experiment produced standing waves in a wire that simultaneously interacted as particles with a stream of electrons. This is an impressive experiment, though it doesn't break the principle of complementarity, as the waves in the wire weren't light, but special vibrations called plasmons. In the future this technique could be used to get information into and out of quantum computers.

WHY SHOULD I CARE? An enhanced understanding of how photons work could lead to the development of powerful quantum computers.

WHAT'S NEXT? A lot more work is needed before practical applications can be developed.



The first photograph of light behaving as a wave and a particle

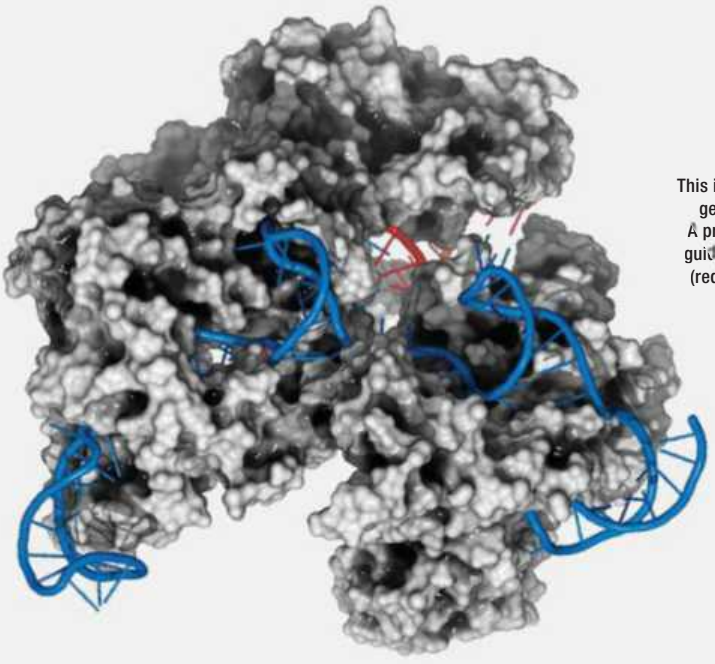
CHINESE DRAGON

At the end of January, a new species of dinosaur was discovered in China, and named Qijianglong, 'the dragon of Qijiang'. The 15m-long herbivorous creature lived 160 million years ago, and had a long neck that comprised nearly half its body length.

MAR

A NEW DAWN

On 6 March, NASA's Dawn spacecraft went into orbit around Ceres, becoming the first craft to visit a dwarf planet. At time of writing it is still mapping the planet's surface from low orbit, and will continue to send back data for many months to come.



This is the CRISPR-Cas9 gene-editing system. A protein (grey) uses a guide (blue) to cut DNA (red) in the right spots

HUMAN DNA EDITED SUCCESSFULLY

The remarkable genetic tool CRISPR (standing for Clustered Regularly Interspaced Short Palindromic Repeat) was developed in 2012. It transformed DNA editing from an expensive, slow process to a rapid, cheap technique. The approach, which employs a mechanism found in the immune system to target specific genes, was used this year for the first time to make modifications to human embryos by scientists at China's Guangdong Province Key Laboratory of Reproductive Medicine and Sun Yat-sen University, Guanghou.

The team was attempting to modify the gene HBB that mutates to cause the blood disease beta-thalassaemia. Although the team was working on embryos with an extra set of chromosomes, meaning that the embryos cannot develop to birth, there were concerns about the ethics of the process if it were ever to be used on viable embryos, as any changes could be passed on to offspring with uncertain results.

Also, the experiment did not produce a successful modification in the majority of the 86 embryos tested. Project leader Junjiu Huang said: "If you want to do it in normal embryos, you need to be close to 100 per cent. That's why we stopped."

Even where the modification worked, there were extra mutations where the CRISPR mechanism made changes to other genes – far more unwanted modification than had occurred in other experiments on mice and adult human cells. This highlights the significant obstacles that stand in the way of using gene editing to eliminate genetic disorders, yet the technique still holds out hope for cures in the future.

WHY SHOULD I CARE? This piece of Chinese research opens up the prospect of 'designer babies' – for good or ill.

WHAT'S NEXT? More research and hopefully some kind of international accord on the ethics involved in the editing of genes.

THEY DID WHAT?

A number of scientists took more unorthodox routes in their research in 2015…

APES WATCHED 'HORROR FILMS'

Kyoto University researchers showed two movies to apes. In the first, a person dressed as an ape leaps out from one of two doors. In the second, a person picks up a hammer and bashes the 'ape'. They used eye-tracking to see what was holding the apes' attention, then played the films again 24 hours later. When watching the first video for a second time, the apes watched the door from which they'd seen the 'ape' jump out. With the second video they stared at the hammer. This proved that apes can store and retrieve information in their long-term memories.

MUSIC COMPOSED FOR CATS

David Teie, a University of Maryland composer, wrote music specifically for cats. Cats approached and rubbed themselves on the speakers much more when they heard the feline compositions than when they were played classical music. The team says that species-specific music could be used to calm animals being kept in zoos or animal shelters.

CHEMISTS UNBOILED AN EGG

A team from the University of California figured out a way of untangling proteins in cooked egg whites and allowing them to refold, as if the egg had been 'unboiled'. First, they hard boiled the eggs. They then liquefied the cooked egg white with urea, before using a 'vortex fluid device' to apply forces to the tiny strands of protein in the white. This separated the proteins back to their clear form. Being able to reform proteins from yeast or E. coli bacteria may lead to better methods for making proteins, which could help create cheaper cancer treatments.

PHOTO: ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE, SCIENCE PHOTO LIBRARY, NASA X2, XING LIDA

SOLE POWER

A team in Canada developed a new material that could make tumbles in winter a thing of the past. The material consists of rubber that's packed with tiny glass fibres. On dry surfaces it acts like normal rubber, but in icy conditions it offers greatly improved grip.

APR

NOT SO DARK

A Durham University team suggested that dark matter may not be so dark after all. They believe they found evidence of dark matter trailing behind its associated galaxy – suggesting the mysterious stuff is interacting with something other than just gravity.

PHILAE WAKES UP

Landing the Philae probe on Comet 67P/Churyumov-Gerasimenko was one of the biggest stories of 2014, with drama erupting as the probe's anchoring harpoon failed to attach, putting it in a slow motion bounce across the surface that left its solar cells shaded from the sunlight. For 60 hours, Philae was active, its 10 instruments sensing and drilling the surface of the comet, but then the probe ran out of power. As 67P continued in its orbit, chunks of the comet's surface were melted by the Sun, letting light reach the lander once more. And on 14 June, Philae's Twitter account carried the message "Hello Earth! Can you hear me?" Rosetta had detected a weak signal from its lander.

The initial link lasted for just two minutes, but was enough to establish that the systems had survived. At the time, the comet was around 215,000,000km from the Sun and 305,000,000km from the Earth, travelling at around 31km/s. Since then, another five contacts have been made with Philae, with the longest lasting around 18 minutes. The information from Philae has been sparse, but has at least enabled a study of the changes in surface temperature. Most surprising of all, analysis of the data revealed that there was oxygen present on the comet in small amounts. After July, Rosetta had moved too far from the comet to have any contact with Philae, though the orbiter has continued to provide information about 67P and may have had one more chance to receive data from the surface around the end of the year.

As for the lander, to quote members of the team, "If you, too, are wondering: will we hear from Philae again? Guess you will just have to wait and see."

The Rosetta mission increased our knowledge of Comet 67P/Churyumov-Gerasimenko

WHY SHOULD I CARE? Because even if you have no interest in astronomy, landing on an object whizzing through space at a top speed of 135,000km/h is mightily impressive.

WHAT'S NEXT? NASA scientists will be analysing data sent back by Philae for several years yet – new revelations may well await.

JUN

BACK IN THE GAME

The Large Hadron Collider was switched back on after a two-year break. During that time, the particle accelerator underwent a major upgrade, doubling the energy of its beams so that it can now collide particles at higher energies.

PAIN-FREE JABS

Students at Rice University, USA developed a new way of giving injections. The device is placed against the skin for 60 seconds while an endothermic (heat-absorbing) reaction occurs inside it, numbing the area so a jab can be given painlessly.

PLUTO'S LANDSCAPE REVEALED

Pluto looked completely different to how it had previously been visualised

WHEN THE NEW Horizons probe launched in January 2006, it received little media coverage. Yet in 2015, after travelling nearly five billion kilometres, this 478kg spacecraft, around the size of a piano, captured everyone's imagination with its stunning images of Pluto. After picking up speed with a slingshot manoeuvre around Jupiter in early 2007, the probe hurtled towards the outer reaches of the Solar System at speeds that peaked at 80,000km/h, yet it took another seven years to reach its destination.

In January, New Horizons sent back the first photographs of Pluto and its main moon Charon, showing them as fuzzy dots. By May, features were beginning to appear in the images, along with Pluto's smaller moons, Nix, Hydra, Styx and Kerberos.

On 14 July the probe made its closest flyby, around 12,500km above Pluto's surface, providing remarkably detailed images of the dwarf planet's topography. Among the discoveries was a large, heart-shaped feature measuring around 1,600km across. New Horizons Principal Investigator Alan Stern commented: "My prediction was that we would find something wonderful, and we did." Despite the complexity of its journey, the probe was just one minute behind its ETA. In October, New Horizons used a 25-minute blast of its thrusters to change course, heading another 1.6 billion kilometres out towards an object called MU69, in the distant part of this region of the Solar System known as the Kuiper Belt.

WHY SHOULD I CARE? Because our knowledge of our own Solar System is still far from complete, and this is a significant new piece in the puzzle.

WHAT'S NEXT? Now that New Horizons has 'done' Pluto, it's moving on to the Kuiper Belt, and should arrive there in 2019.

Pluto's landscape includes icy mountains, stretching to heights of 3,500m

DINO CRAZY

The arrival in cinemas of Jurassic World in June saw the world go briefly dinosaur-mad. The result was a short-lived publicity boom for the likes of Dr Beth Shapiro at University of California Santa Cruz and others looking the possibility of reviving long-extinct species.

BYE BYE, BIG CAT

On 16 June, the US Fish and Wildlife Service declared the eastern cougar (Puma concolor couguar) extinct. But don't be too upset: there hadn't been a confirmed sighting since the 1930s, and not all zoologists acknowledged the subspecies in any case.

BLACK-FOOTED FERRET SAVED FROM EXTINCTION BY FROZEN SPERM

There is much talk of reviving extinct animals such as mammoths from frozen DNA. While this is still some way from being possible, 2015 saw an endangered species put on the road to recovery using decades-old frozen sperm.

The black-footed ferret, a North American mammal, was already in severe danger of extinction when 18 of them were put in a captive breeding programme back in the 1980s. The sperm of six ferrets, including that of one called 'Scarface', was frozen. Then in August this year, Scarface became a donor father, even though he died around 20 years ago. The frozen sperm was successfully used by American zoos and the Smithsonian Institute to artificially inseminate living females, therefore improving the species' chance of survival by boosting genetic diversity in the tiny population. By adding fresh genes, the risk from inbreeding has been reduced.

The current breeding programme has helped the ferrets reach a population of around 300.

WHY SHOULD I CARE? The technique pioneered in black-footed ferrets could be used to help save other endangered species.

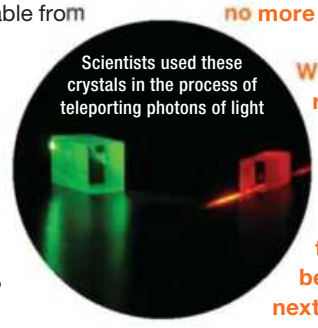
WHAT'S NEXT? A more concerted global effort to build biobanks of animal sperm and eggs looks increasingly like the smart move.

PHOTO: SMITHSONIAN CONSERVATORY BIOLOGY INSTITUTE, GETTY, SCIENCE PHOTO LIBRARY X2, BARTEK WACLAW/MARTIN NOWAK, BRIAN LEANDER/GREG GAVELIS, PHIL/US GOVERNMENT

QUANTUM TELEPORTATION RECORD SMASHED

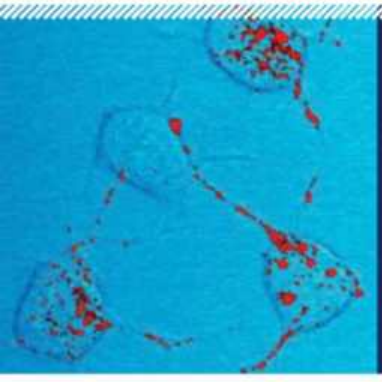
Quantum entanglement took a big step forward this year. In this small-scale version of a *Star Trek* transporter, properties of a quantum particle are transferred to another remote particle. The remote particle becomes indistinguishable from the original. This is only possible using a mix of the spooky connection of entanglement and conventional data transfer. The US researchers achieved teleportation along a 100km optical fibre link, four times the previous record. Teleportation keeps the data intact, which is crucial for quantum computers and quantum encryption.

WHY SHOULD I CARE? It could lead to unbreakable encryption – no more hacked bank accounts!



Scientists used these crystals in the process of teleporting photons of light

WHAT'S NEXT? Chinese researchers are planning a long-distance communication experiment that will teleport particles between satellites in the next couple of years.



CANNIBAL CLUE

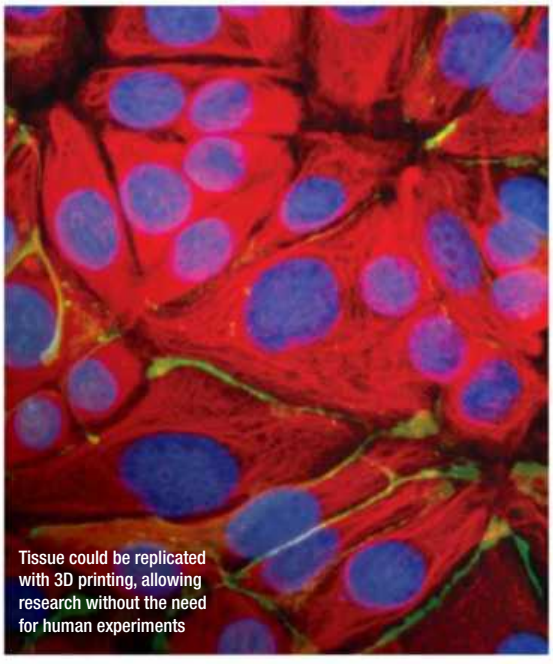
Papua New Guinea's Fore tribe, who ate human brains until the 1950s, have developed a natural resistance to kuru, a form of encephalopathy. Understanding how this new-found immunity developed could lead to treatments for CJD, Alzheimer's and Parkinson's disease.

JUL

TINY EYES

Warnowiids are tiny, single-celled marine creatures – yet in July it was discovered that their bodies contain a structure that's remarkably similar to the human eye. It demonstrates that natural selection can reach a single design through different evolutionary paths.

Frozen sperm has helped secure the future of the black-footed ferret



Tissue could be replicated with 3D printing, allowing research without the need for human experiments

SCIENTISTS CREATED 3D PRINTED HUMAN TISSUE

Experimental 3D printing of human tissue has been underway for some years, but 2015 saw real breakthroughs. A team from the University of California, San Francisco used a revolutionary technique called DNA Programmed Assembly of Cells to produce tiny models of living structures containing several hundred cells.

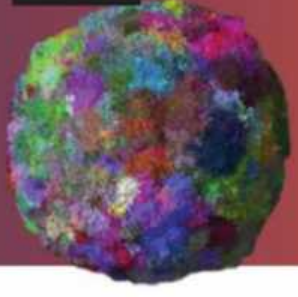
Within a decade it could be possible to build a living model of a cancer patient's affected organ, which could be used to test drugs for side effects.

WHY SHOULD I CARE? It opens up a world of research possibilities, without the need for human experiments.

WHAT'S NEXT? Longer term, it could be possible to grow complete organs, which would slash the length of transplant waiting lists.

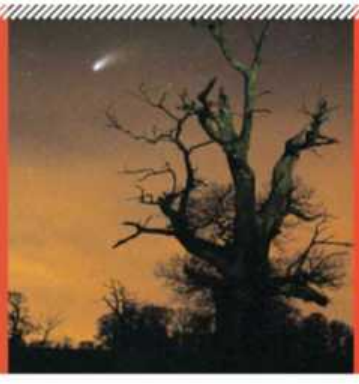
The new technique called DNA Programmed Assembly of Cells used tiny 'biobricks', not unlike Lego, to build human tissue

AUG



BATTLING CANCER

Scientists at Harvard, Johns Hopkins and Edinburgh produced the first 3D computer model of how tumours grow and mutate. It's hoped the model will enable more effective treatments.



ORIGINS OF LIFE

Japanese researchers modelling the effects of high-power collisions on amino acids found that such impacts could trigger the production of peptides – suggesting that a comet impact may have been the spark that ignited life.

LIQUID WATER FOUND ON MARS BRED USING FROZEN SPERM

It has been known for some time that there was water on Mars, notably in the polar ice caps. However, Mars has a combination of a very low atmospheric pressure – which means that any liquid water quickly evaporates – and an average surface temperature of around -63°C, making liquid water unlikely to form in the first place. It was, then, a major surprise when NASA announced evidence that there is flowing liquid water on the surface of the planet.

While no water was observed on the move, scientists found dark, narrow streaks a few hundred metres long, running down gulleys, which appeared to 'ebb and flow over time'. These are likely to have been produced by flowing water, especially as hydrated salts have been discovered on those slopes. These chemical compounds containing water are likely to have formed while liquid water was present.

The deposits were discovered by the Mars Reconnaissance Orbiter. This craft uses an imaging spectrometer, which detects the presence of different chemical structures from the light reflected by them. If the compounds were dissolved in the water they would lower the freezing point, in the same way that salt does when spread on ice, enabling the water to stay liquid despite being well below 0°C. As NASA's John Grunsfeld put it, "Our quest on Mars has been to 'follow the water' in our search for life in the Universe." This discovery will provide an important focus for future attempts to find life on Mars.

WHY SHOULD I CARE? The presence of water makes the presence of life – of some kind, at some point – a much more viable proposition.

WHAT'S NEXT? We're getting to a point where probes and landers have told us all they can about Mars – now we need to actually go there.

PHOTO: NASA/JPL-CALTECH X3, NATIONAL GEOGRAPHIC MAGAZINE, GETTY X7, ISTOCK X2

OCT

ALONE AFTER ALL?

New research published in October suggested that while there may be millions of Earth-like planets, Earth itself is one of the oldest – and that most habitable planets have yet to be formed. So no aliens will be arriving soon…

INSIDE JOB

NOV

French football team FC Nantes revealed that it has been tracking players' internal temperature during matches using an ingestible pill that sends data to a nearby receiver. They were researching the effects of ice therapy on recovery times.

HUMAN-LIKE SPECIES DISCOVERED

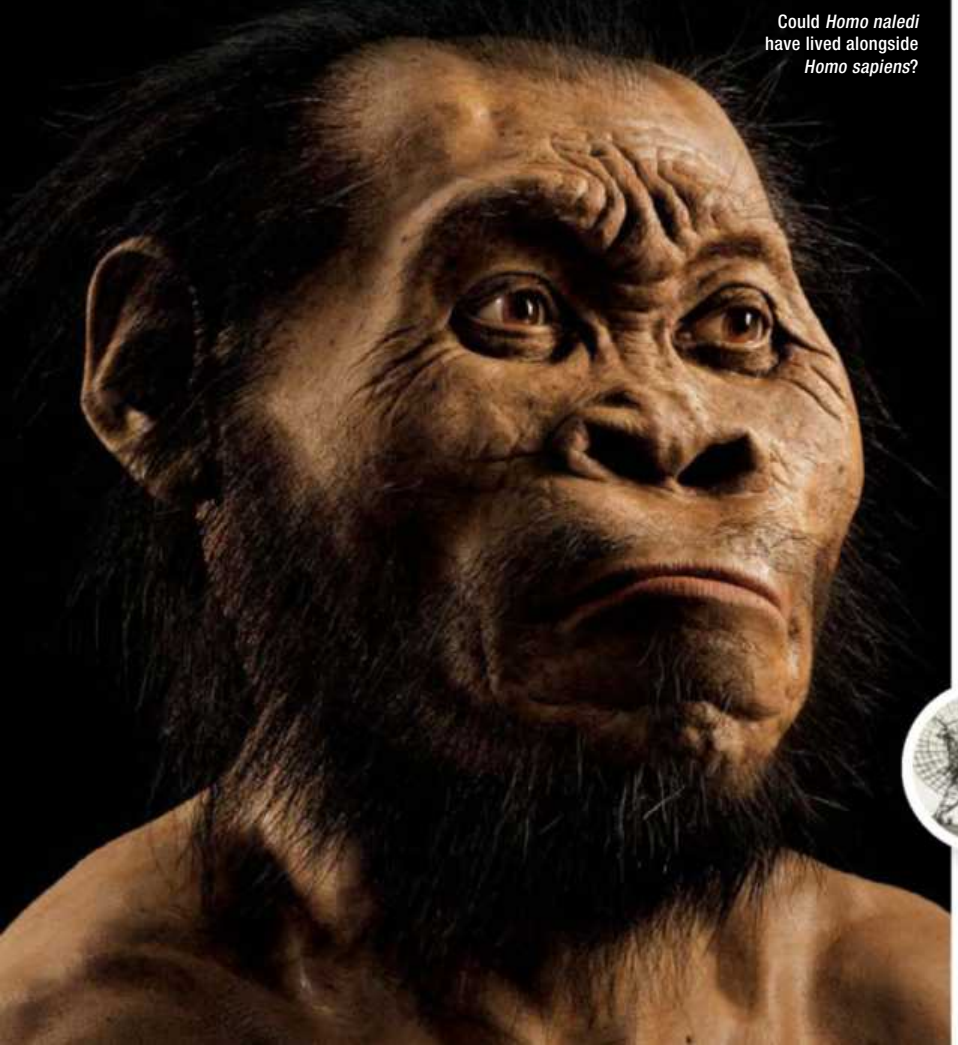
The discovery of a new human species is bound to make news, but it takes time to go from finding fossils to a clear scientific result. It was back in late 2013 that a team led by Lee Berger of Witwatersrand University, South Africa, followed up a sighting by cavers in a concealed chamber in the Rising Star cave system. The caves are around 29km from Johannesburg, in an area that has been given the nickname 'the cradle of humankind', as many fossils from early humans have been found there.

In total, a remarkable 1,500 fossil fragments were removed from the cave, and this year the world discovered what they found. The bones made up the partial remains of 15 separate individuals of an early human species. Homo naledi, as the hominins have been called, appears to have walked upright and reached around 1.5m in height, but had hand and shoulder structures suggestive of spending considerable time in trees.

The skeletons had a mix of features, with a skull that suggested a brain around one-third the size of ours but with feet that looked surprisingly modern. The next step is to discover how old these bones are. H. naledi could be early humans, dating back two to three million years, or could be a relict that survived to coexist with Homo sapiens.

WHY SHOULD I CARE?
Because humankind's come a long way… aren't you curious to know how we got here?

WHAT'S NEXT?
The exact age of the *H. naledi* still needs to be verified, so that's the priority right now.



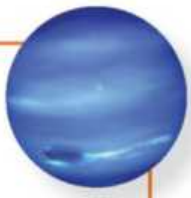
Could *Homo naledi* have lived alongside *Homo sapiens*?

BEST OF THE REST

2015 wasn't the only great year for science…

1543 The publication of Nicolaus Copernicus's (pictured) *De Revolutionibus Orbium Celestium* and Andreas Vesalius's *De Humani Corporis Fabrica* revolutionise the worlds of astronomy and medicine.

1846 US dentist William Morton pioneers the use of general anaesthetic, while in Germany, Johann Gottfried Galle and Heinrich Louis d'Arrest are the first to identify the planet Neptune.



1907 Leo Baekeland (pictured) invents Bakelite, the first synthetic plastic, while Ivan Pavlov conducts his experiments regarding conditioning.

1913 Our understanding of the elements leaps forward, thanks to Henry Moseley defining atomic numbers and Niels Bohr (pictured) coming up with a new model for atomic structure.

1917 Ernest Rutherford (pictured) splits the atom, spawning the discipline of nuclear physics. In France, US army surgeon Oswald Hope Robertson pioneers the use of blood banks.

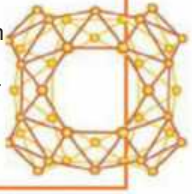
1927 Werner Heisenberg lays the foundations for quantum mechanics with his uncertainty principle. That year, the first transatlantic telephone service is also introduced.

1953 James Watson and Francis Crick describe DNA. The Miller-Urey experiment shows how the first amino acids may have formed.

1961 Russia's Yuri Gagarin (pictured) becomes the first man in space. Back on Earth, the World Wildlife Fund is established by biologist Julian Huxley and ornithologist Peter Scott.

1967 At Cambridge University, Jocelyn Bell Burnell discovers the first pulsar. And speaking of things that pulse, South African surgeon Christiaan Barnard carries out the first human heart transplant.

1985 A hole is identified in the ozone layer over Antarctica by Farman, Gardiner and Shanklin. In the US, a team led by Howard Kroto discover the buckyball molecule.



BRIAN CLEGG is a science writer and author, whose most recent book is *Science For Life*

INVASION OF THE LIONFISH

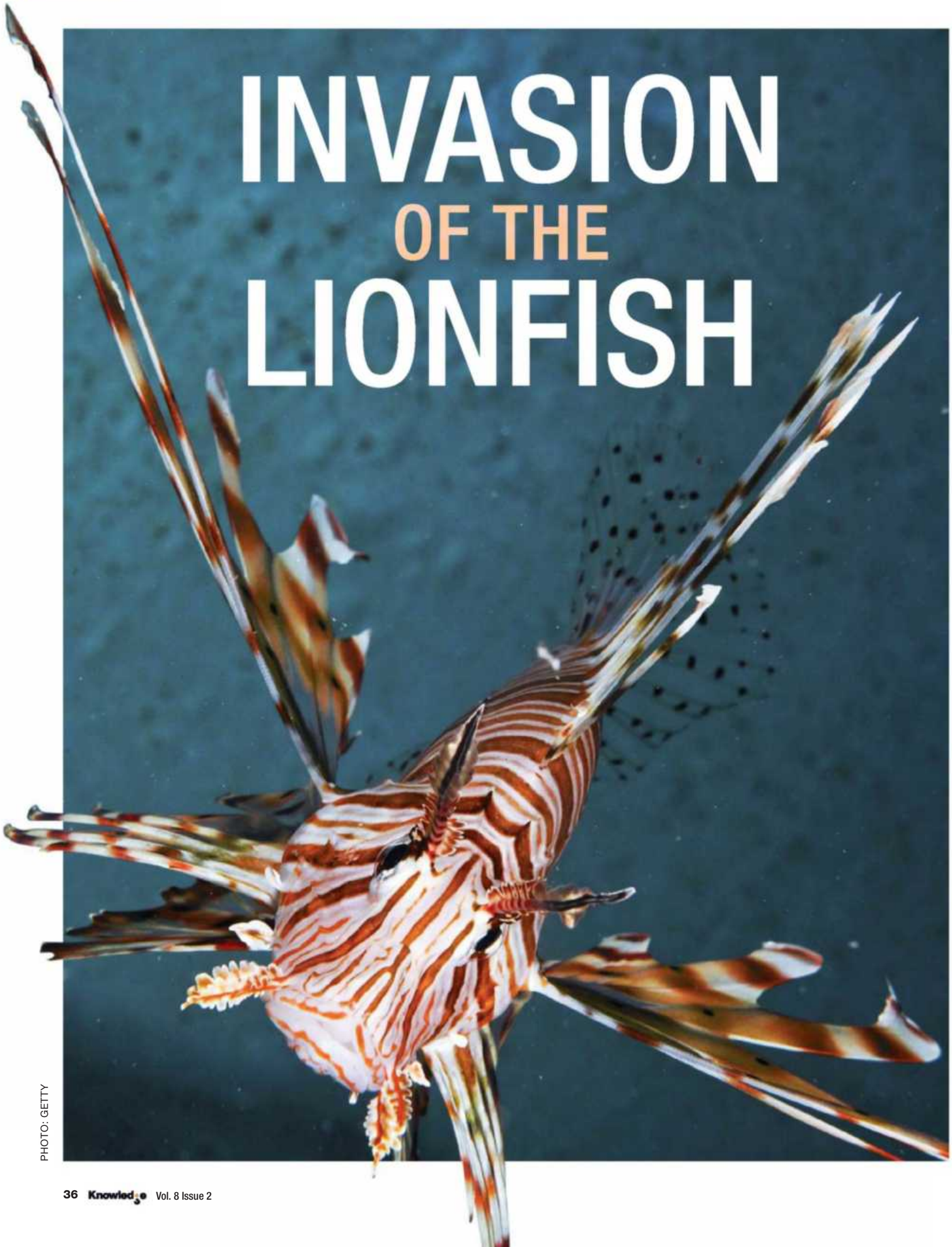


PHOTO: GETTY

Invasive lionfish are wreaking havoc on the reefs of the western Atlantic and the Caribbean. So what can we do? Well, we could eat them, says Helen Scales

While scuba diving on the coral reefs surrounding Abaco Island in the Bahamas, I spy a lionfish fluttering in the distance. These graceful animals, with their shroud of venomous spines, normally live on the other side of the world. But here they're considered to be menacing pests. I watch the creature hovering in front of me and feel strangely conflicted – it is beautiful, but it has to go. It doesn't flinch as my dive buddy skewers it with a long metal spear. This lionfish will be cooked and eaten, and conservationists are encouraging other people to tuck in to the tasty fish in an attempt to control the spread. But some are also trying to persuade other fish-eaters to get in on the act, including those most toothsome predators: sharks.

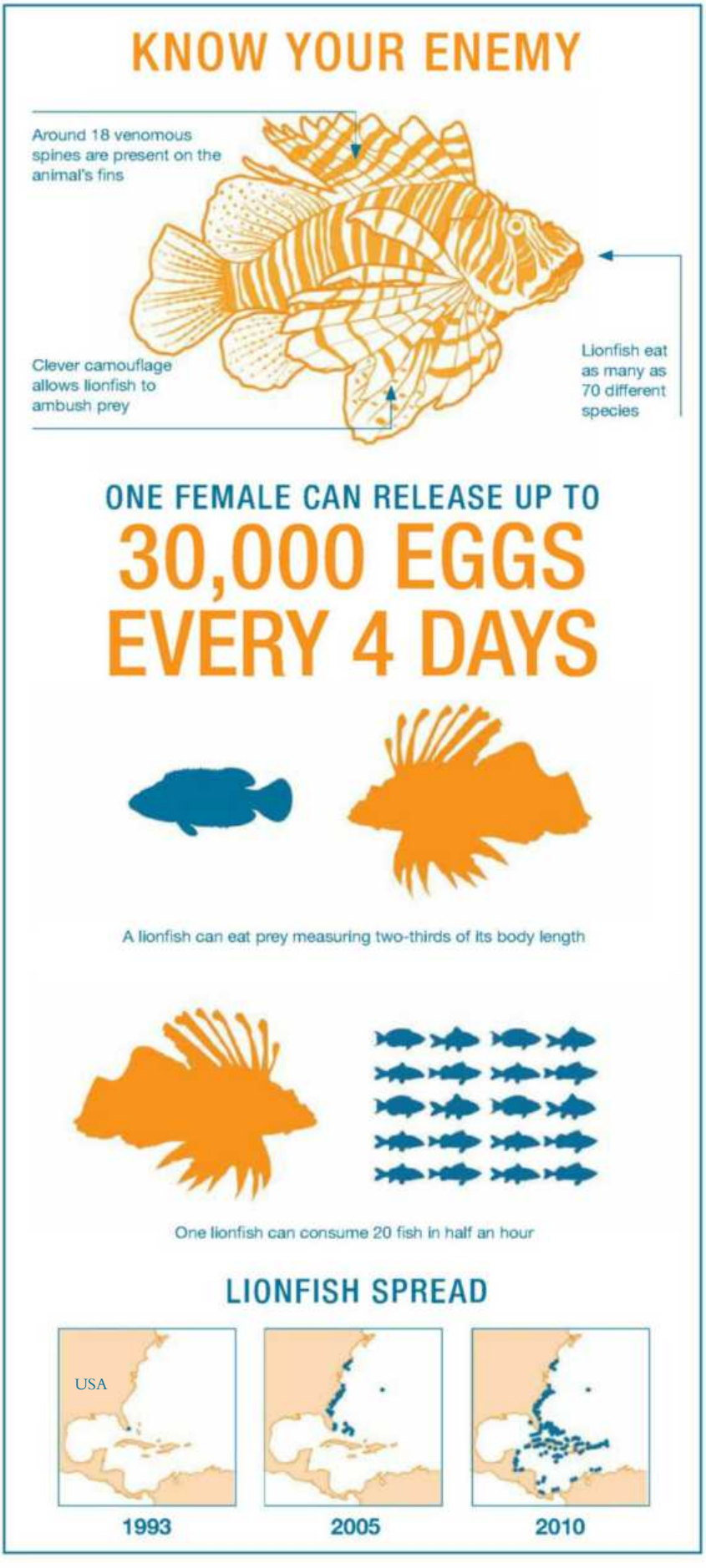
Invasion of the seas

Experts blame the lionfish problem on the pet trade. It most likely began when captive fish – perhaps as few as 12 individuals – were released from aquariums in Florida. When those founding fish began to proliferate, people got worried. Lionfish are skilful hunters with enormous appetites. In their new territories they started to gorge themselves on numerous species of smaller fishes and invertebrates, some of which were already threatened before the arrival of the invaders. The concern was that the lionfish could strip coral reefs bare, devastate local ecosystems, damage tourism and impact local fisheries in one fell swoop. There was little time to investigate the matter before lionfish scattered far and wide.

In 2007, a single lionfish showed up in a group of remote Cuban islands called the Gardens of the Queen. Divers flocked to photograph the fish, but it wasn't alone for long. "Within a matter of weeks we had 10 places where we could see lionfish," says Cuban marine biologist and diver Andrés Jiménez Castillo. "Now they are everywhere."

Lionfish are formidable invaders. They can spawn throughout the year and just one female can release up to 30,000 eggs every four days. These floating clumps of eggs ride ocean currents for up to a month, drifting hundreds or even thousands of miles before they hatch and form a whole new generation of lionfish.

As the lionfish swept through Cuban reefs, Castillo and his colleagues began to notice that fewer were spotted at dive sites where there were lots of



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Lionfish measure up to 48cm in length and occur at much higher densities in their invasive range than their native habitat

sharks. They wondered if perhaps the sharks were eating lionfish and landed on the idea of giving them a helping hand.

A search for solutions

The native range of the lionfish stretches throughout the Indian and Pacific Oceans. Here, they are hunted by groupers and sharks. In the Caribbean, however, predators aren't used to seeing the spiny fish and don't seem to hunt them. Nevertheless, when they were offered a lionfish on the end of a diver's spear, the Cuban predators soon caught on.

Castillo saw that groupers, especially the metre-long Nassau groupers, quickly learned to grab lionfish from his spear and swallowed them whole, spines and all. They even started following divers around and hovering expectantly next to lionfish, apparently waiting to be fed. In contrast, the sharks have been more reluctant. "You can see they don't like it," says Castillo. Sharks tend to pick at a dead lionfish, spitting it out repeatedly and turning it around in their mouths before trying to swallow it.

So will sharks help to control numbers of the invasive lionfish? It's debatable whether they will get a taste for this exotic prey and start hunting lionfish of their own accord.

"There is evidence to suggest that another predator is effective in reducing lionfish numbers: humans"

It could be too late for sharks to leave their mark on the lionfish invasion. Some scientists think that if Caribbean reefs hadn't been heavily overfished by the time lionfish came along, the invasion might not have been so bad. Perhaps healthier populations of predatory fish could have helped stop lionfish in their tracks. One study conducted in the Bahamas supports the theory that reefs with higher densities of predators had fewer lionfish, as Castillo saw in Cuba. But not everyone agrees.

"A lot of people think predators are the solution," says John Bruno, a marine biologist from the University of North Carolina and co-author of a

PHOTO: ANTONIO BUSEILLO X2, MICHELLE NICOLE LOWE, LIONFISH UNIVERSITY/STORYFUL, SUE DALY/NPL

Attempts to encourage sharks to eat the lionfish have been unsuccessful

A three-pronged spear prevents the lionfish sliding down the pole and injuring the diver

Lionfish University photographed this grouper eating an invasive lionfish

Sharks don't seem to recognise the lionfish as prey

region-wide lionfish study. His team's research paints a different picture. On 71 reefs, from the Bahamas to Belize, they found no relationship between the density of lionfish and native predators. What they did find was evidence to suggest that another predator is effective in reducing lionfish numbers: humans. Bruno and colleagues consistently saw lionfish in lower densities inside marine protected areas – not because of abundant sharks, but most likely because reserve managers organise regular culls.

Lionfish derbies have become popular across Florida and the Caribbean where divers compete to catch as many lionfish as possible on a single day, from dawn until dusk. Cash prizes are up for grabs for catching the smallest and largest lionfish. The numbers caught can be staggering. During the 2013 derby on Green Turtle Cay in the Bahamas, 62 divers brought back 1,204 lionfish. Lionfish have venomous spines that can cause extreme pain, nausea and breathing difficulties in humans. Once these spines have been removed, however, the fish can be filleted just like any other fish. In Cuba, though, eating lionfish is something Castillo no longer gets to do.

"It's very hard for us to catch them for food," he explains. "The sharks don't allow us to leave the water without giving them the lionfish we've caught." With the situation getting potentially dangerous, Castillo has stopped hunting lionfish to feed to local sharks. Other conservation groups, such as Florida-based Team Frapper, are trying another tactic and are attempting to design lionfish-specific traps to capture the invaders.

Lionfish can be safely cooked and eaten, once the venomous spines have been removed

What next?

Plenty of unknowns remain in the unfolding story of the lionfish invasion. Their appetite for native fish is proven, but the effect this has is contentious. One study in the Bahamas showed that from 2008 to 2010, local fish populations crashed by 65 per cent as lionfish increased. Elsewhere, effects have been harder to find. One thing most experts agree on is that lionfish are in the western Atlantic for good. As other invasive species have shown, there's little chance of eradication. We may just have to wait and see the long-term effects of the invasion. But until then, if you see lionfish on the menu in the Caribbean, why not give it a try? ■

HELEN SCALES is a marine biologist, author and broadcaster whose latest book is *Spirals In Time*

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THE END OF WORK?

According to a new report, advances in artificial intelligence and robotics mean that soon, most of the jobs we do today will be automated. Will that leave us jobless, or will it free us from the 9 to 5? Russell Deeks finds out

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PHOTO: GETTY

There's been much talk lately of an 'existential threat' from artificial intelligence systems, particularly those embedded within robots. Make machines smart enough, goes the theory, and they'll soon realise that they could run Planet Earth a lot more efficiently without those pesky, meddling humans.

But while such a future 'singularity' may be a terrifying prospect, it's also not likely (most experts agree) to happen any time soon. Meanwhile, there's another, slightly more prosaic question that's often overlooked: never mind robots destroying our species, what exactly are we going to do when they've taken all our jobs?

We have invited a group of AI and business experts to discuss that question. We were struck by Appvance CEO Kevin Surace's recent TED talk, in which he paints a compelling picture of a future in which none of us have to work and we're all free to dedicate our lives to art and education. Over these pages, Kevin expands upon his ideas, while AI experts Mateja Jamnik from the University of Cambridge and Andrew Lea of the British Computer Society discuss whether the current state-of-play in AI research matches up with Kevin's vision, and Jon Andrews of management consultants Price Waterhouse Coopers (PwC) offers a view from the business world.

As you'll discover, there's no broad consensus on how new technologies will impact upon our working lives. But all our experts agree on one thing: the times, they are definitely changing…

KEVIN SURACE
CEO, APPVANCE

There is no doubt in my mind that in the next 10, 20, 50 years, most of the jobs that we know today are going to disappear, because it will be cheaper, quicker and far more efficient to have those tasks carried out by robots and artificial intelligence. But as I see it, the huge wave of disruption that's coming presents humanity with a great opportunity.

The kinds of disruption I'm talking about are already happening – in many cases, without people even realising it. Take driverless cars: to most people they still seem futuristic, but they'll be on the road in most parts of the world by 2020, and by 2030 human-based cars will be outlawed in many cities, no question. The Bay Area in San Francisco already has driverless buses on certain routes. So people need to wake up and start thinking about how many millions of people around the world are employed in driving things – because that's all gone in 10 years' time.

You can also look at the catering industry, where many restaurants are using digital ordering via an iPad rather than a human waiter, and the hotel industry, where the Savioke robot butler brings towels to your room. Robots like Savioke will soon be able to deliver your food, too, while kitchen processes are becoming so automated that

Google has put its self-driving equipment into a number of different car brands

PHOTO: GETTY X2, PRESS ASSOCIATION

in the next five years you'll see burger outlets actively touting the fact that no human has touched your food. And it can be custom-made for you, at a quarter the price of the hamburger joint across the street… that will take off, no question.

Those are the easy examples we can point to right now. Doctors are the ones people laugh at, but there are already robots run by doctors today; you could take the same robot, run it by a computer and it would do a better job. You can program the computer for every possible situation that could occur in the human body, and it will make all the trade-offs in 10 milliseconds that a doctor would take a minute to make. You're already dead by then! It's only really the FDA that's stopping us from doing computerised surgery already – it's not a technology problem any more, it's a regulatory problem and a psychological one.

So all these things are happening already, and our world is going to change drastically.

Above: In Canada, some restaurants allow guests to place their food orders digitally – could this be the end of waiting staff?

Change is a-coming

We've seen this situation before, of course. In the agricultural age, over 90 per cent of the population worked in farming. They couldn't imagine what would happen if most of their jobs were taken over by machines. Today, just 1.5 per cent of people in the US work in agriculture, and the rest found jobs elsewhere – making the machines and doing other things. So we were able to reinvent jobs in the past, including when manual labour was taken away. We did manage to break through those walls, but from one side of the wall no-one could ever see what lay on the other side.

The difference, though, is that now we've got machines that can take over virtually *every* manual task, and they're beginning to take over many mental tasks, too – all at higher quality and lower cost. So that does make us ponder what seven billion people on Earth will do with themselves. It could be that learning becomes more valued, and that's how you earn a living… or it could be that the concept of 'earning a living' itself is in fact outmoded, that there's a different kind of utopia. In my TED talk I suggested that we could enter a new Renaissance, where work in the traditional sense is not what's valued any more, but there's great value in art.

Some people have said that's a ridiculous dream, or that the only people who'll have jobs will be the robot overlords. I prefer to think that, as humanity moves forward, there'll come a time where humanity learns to take care of itself in a new way. But everybody needs to wake up to the fact that this is coming. Little by little, jobs will be taken from people, and we need to start thinking about what those people are going to do. There's about 20 per cent of people in any society that can only really do manual labour, and we probably can't teach them to program computers. So what will these people do? What can we all do so that we're contributing in a new way, and what will those contributions be?

There are still certain barriers to all this, of course. One barrier that's been overcome already is cost: it's now cheaper to manufacture goods using robots than with Chinese labour, which is among the cheapest in the world. But there are still big steps forward needed in the field of AI, and there have to be breakthroughs in societal norms, too. In fact, the latter could be the biggest hurdle. But these changes are definitely coming: not next year, but not in 100 years, either. We're looking at 10 or 20 years down the line… 50 at the most.

What's just over the horizon isn't necessarily a techno utopia – it could turn out to be a techno nightmare. But it *is* the techno future, and we need to be having these conversations now.

Right: The Savioke robot distributes towels in hotels and can even navigate between floors

Delivery drones wouldn't mind working the weekends…

MATEJA JAMNIK

SENIOR LECTURER, UNIVERSITY OF CAMBRIDGE COMPUTER LABORATORY

Having gone through a 40-year 'AI winter' after too many inflated promises were made in the 1970s, artificial intelligence is getting academics and industrialists excited once more. Google, for instance, recently purchased the AI company Deep Mind for a reported $400m, and is also developing a driverless car, while Amazon is investing heavily in the drone delivery system.

With news stories about drones carrying our parcels, and humanless factories in China, it's not surprising that many people are concerned about what is going to happen to their job. The most pessimistic studies predict that as many as 47 per cent of jobs will disappear in the next 20 years. So, will robots replace us and take all our jobs, doing them better, faster and cheaper to boot?

I don't think they will – but they will change the way we work. The artificial intelligence systems of the future will have a profound effect on what we do and how we do it, much as the Industrial Revolution affected manual jobs of the 19th Century, and the digital revolution transformed communication in the 20th Century.

A lot of repetitive, menial work will disappear and be replaced by automated robots. But this is not a bad thing: many of those jobs are soul-destroying and often injurious to health, and there's a shortage of people who want to do them. Potentially threatened jobs might include factory workers, accountants, postal workers and human translators, to name a few.

But the main drive in artificial intelligence is to develop smart systems that will work *with* people. Big data, machine learning and super-computing power enable systems to find patterns far quicker than humans can. At the same time, we are developing systems that are getting better at cognitive tasks. In my own work, I'm modelling human intuitive reasoning, in particular with visual information, to enable machines to discover and learn new knowledge. I'm essentially humanising computer thinking.

I see the future in the hands of human experts, but heavily supported and helped by intelligent systems that are becoming more accurate all the time. Machines will assist and collaborate with humans to enable them to work more effectively as well as do things that are beyond human capability alone. In biomedicine, for example, intelligent systems can exploit multi-source big data to build models of complex patient cases with lots of co-occurring medical conditions.

However, as intelligent systems become ubiquitous, many ethical and safety issues arise. For example, who takes responsibility for a wrong or harmful decision by a computer program? While we have significant evidence that software can sometimes be more reliable than humans in making crucial decisions, I think that for the foreseeable future these systems will mostly be designed to collaborate with human experts, not replace them.

PHOTO: GETTY X3, SCIENCE AND SOCIETY, MARCUS GINNS PHOTOGRAPHY

AUTOMATION THROUGH THE AGES

The spinning jenny was invented in 1765 and was still in use in the 20th Century

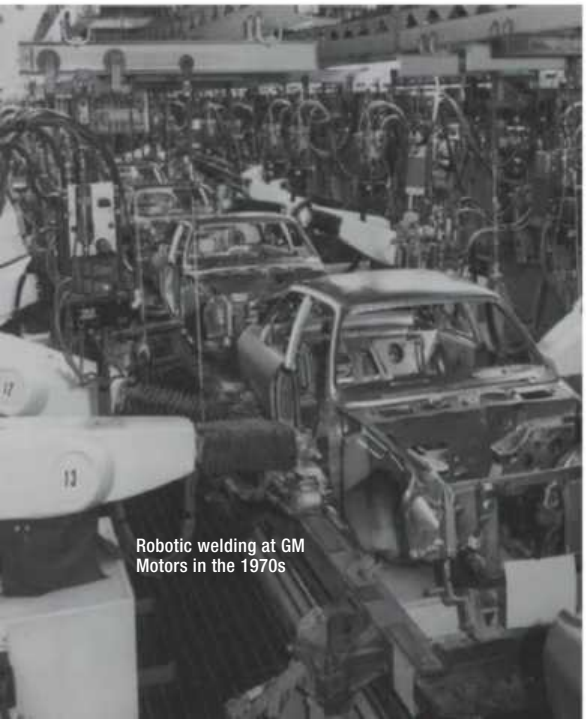
INDUSTRIALISATION

The first electronic computing machines emerged in the 1940s, with the programmable, all-digital Colossus machine at Bletchley Park arguably the first modern computer. By the early 1950s they were finding their way into offices, and as computing technology has continued to evolve over the years, they've taken on more and more previously 'human' tasks. While this has led to mass redundancies at times, the birth of computing has also created entire new industries.

COMPUTERS

Until the mid-18th Century, goods were manufactured by hand in small workshops, often in people's homes. The invention of the steam engine, the spinning jenny and machine tools changed all that, leading to the large-scale mills and factories we're used to today. But the new technologies weren't popular with everyone, and in the early 19th Century the Luddites in northern England took to sabotaging the machines that were taking away their jobs.

Operating a mainframe computer in the 1960s



Robotic welding at GM Motors in the 1970s

FACTORY ROBOTS

In 1961, a programmable robot arm designed by George Devol and Joseph Engelberger was given the job of welding diecast parts onto automobile bodies on a General Motors assembly line in New Jersey. 'Unimate', as it was called, was the first production-line robot and paved the way for the widespread automation of manufacturing processes that took place in the 1970s and 80s and continues to this day.

1ST CENTURY AD
Heron of Alexandria builds human-shaped automata

1941
Konrad Zuse builds the first programmable computer, the Z3

1941
Isaac Asimov's short story Liar! introduces his Three Laws of Robotics

1950
Alan Turing proposes 'the Turing test' to measure computer 'intelligence'

1951
Chess and draughts programs run on the Ferranti Mark 1 computer at Manchester University

1956
The term 'artificial intelligence' is used for the first time, at a conference at Dartmouth College in New Hampshire

1959
MIT founds its AI Lab

1961
Unimation Unimate robot starts work at a General Motors factory

1979
Backgammon-playing program BKG defeats the world champion

1986
First robot cars produced at the University of Munich

1997
Deep Blue supercomputer defeats chess champion Garry Kasparov

1997
The first RoboCup – a football tournament for robots – is staged in Nagoya, Japan

1999
Sony starts selling the AIBO 'robot dog'

2002
The iRobot Roomba vacuum cleaner goes on sale

2005
Ray Kurzweil predicts machines will be smarter than humans by 2045

2009
Google builds its first self-driving car

2011
Siri, Google Now and Cortana launch

2015
First robot-staffed hotel opens in Japan

ANDREW LEA
FELLOW, BRITISH COMPUTER SOCIETY

If you want to discuss the impact of artificial intelligence on the world of work, you first need to look at what the phrase actually means. Artificial intelligence today consists of several discrete disciplines, resting on independent theories. A few current uses include: image recognition and neural nets for self-driving cars, optimised search algorithms, playing chess or planning routes, and recommendation engines in personal assistants. And there are many more.

Just as particle physics is searching for a 'theory of everything', so AI lacks (but is generally not searching for) a 'universal theory of thinking'. Having emerged from several decades in which AI was poorly regarded – partly due to failing to deliver on early over-expectations – AI is now finding practical applications. Insights emerging from such applied AI may eventually give rise to that theory of thinking.

Today, special purpose machines can displace people from specific manual tasks (digging tunnels with shovels, or walking from here to there) but the tools (the diggers or cars) are still controlled by people. So it is with computers: they've displaced us from specific tasks (adding numbers), but still need people to drive the spreadsheet. Machines and computers need people to decide to do anything: that is, to supply the initiative. Perhaps a general purpose machine, able to displace us from our work, requires general purpose AI.

Unexpected item in the bagging area! We're all familiar with the cry of these robots…

The da Vinci surgical robot can carry out minimally invasive operations

This self-service McDonald's machine in Manchester, UK, allows diners to order food

If so, what capabilities would that AI need? It would need a flexible, temporally aware reasoning system, able to call upon the special purpose sub-systems above. It would learn through training (supervised learning) and experience (unsupervised learning). It would need first class language understanding, able to cope with humour, sarcasm and contradictions. Initiative and self-motivation may require an awareness of self, possibly giving rise to emotions and even ethics. Finally, it may be able to program itself.

There are two possible routes to this kind of AI. Firstly, developing a theory of thinking and then engineering it. Secondly, setting up environments in which AI evolves through natural selection, without us understanding how it works – just as we don't understand how we ourselves think. It might sound far-fetched but this discipline, genetic programming, already exists.

An AI capable of these feats could pass a strong version of the Turing test: it could be given the rules of a new game in spoken English, and play it. It could decide to read this article, disagree with it, become bored and stop. But AI of that level – the kind of AI that might put us *all* out of work – is still some way down the line.

Surgeons in China control a da Vinci robot during an operation

JON ANDREWS
GLOBAL PEOPLE AND ORGANISATION LEAD, PWC

Last year, PWC produced a report entitled The Future Of Work: A Journey To 2022. It draws on five years of research and points to three potential future trends: a 'blue world' of huge corporations built on an employee base that works for them their whole career; an 'orange world' where most employment is on a freelance or short-term contract basis; and a 'green world' where a company is defined more by its corporate and social responsibility. All these scenarios are impacted by the digital revolution, and the pace of change is creating an unpredictable environment for employers and employees.

With advances in robotics and AI, we will definitely see more automation – including automation of things that people wouldn't dream of being automated today. But I don't believe that work itself is suddenly going to disappear – we've been promised 'the leisure society' several times before and we're still waiting for our Jetsons-style flying cars! History teaches us that when machines take away the need for manual labour, other jobs spring up to fill the vacuum. For instance, maybe drones can fight wars for us now but you still need human beings to build and service them, as well as IT security experts to keep them safe from hackers. As old jobs start to vanish, new jobs emerge that we hadn't previously imagined.

Technology advances will also change how and where people work. I believe that technology will empower the rise of the portfolio career – people will have their own brands and sell their skills to those who need them, where they need them. And much of this work will take place virtually.

That points to another change that's coming: if we're all going to live longer, then we'll have to work longer, too. If somebody born in 2012 is going to live until they're 105, then they'll probably have to work until they're 85. It'll be a different sort of career: people might retire in the middle of it, they might have more flexible working and so on. We could see the rise of the part-time pensioner.

One thing is certain in this dramatically shifting world of work – change *is* coming, and there are lots of questions that both employers and employees need to start asking themselves as we prepare for a world in which machines, artificial intelligence and human beings work side by side. ■

RUSSELL DEEKS is a freelance science and technology journalist, and Contributing Editor at *BBC Focus*

PHOTO: GETTY X4, PWC

A winter's tale

When the cold weather descends on the Highlands, locking the land in ice and snow, only the toughest survive. Stephen Moss looks at the species that endure the bleakest months in Britain's wildest corner

Photos by Laurie Campbell

Standing stock-still on a thick carpet of frosty bracken in Mar Wood, Deeside, a red deer eyeballs the photographer. Now that the autumn rut is over he must concentrate on feeding in order to regain his strength and prepare for the hardships to come. In winter red deer develop thicker, darker coats, and move from exposed moorland to lower ground, seeking shelter in the forests

Shrouded in deep snow and blasted by freezing winds, the Scottish Highlands is a punishing place for wildlife in winter. Temperatures plummet to well below freezing, the vegetation is locked in frost and the coastline is pounded by ferocious storms and gales. But a rich and surprising variety of wildlife manages to tough out these long, harsh months, adapting effectively to the conditions to survive to breed again in spring.

Days are short this far north, meaning that finding food is always a priority. On higher ground, reindeer forage patiently in the drifting snow for lichen, while golden eagles patrol the skies in search of mountain hares and ptarmigan, hard to pick out in their winter whites. These majestic raptors, voted Scotland's national wildlife symbol in 2013, also scour the landscape for red deer that have succumbed to the bitter conditions.

In the great Caledonian pine forests of Strathspey, red squirrels seek out the supplies they cached in autumn, with the unwary ending up as a meal for opportunistic pine martens. A handful of Scottish wildcats still prowl these trees, too, remaining elusive and largely out of sight.

Small birds – tits, goldcrests, finches, nuthatches and treecreepers – gather in noisy feeding flocks at this time of year, seeking warmth and safety in numbers. As they pass through the forest canopy they utter a constant volley of high-pitched contact calls to knit the group together, switching rapidly to sharp and urgent warning notes should they spot a sparrowhawk or other predator.

But even in the depths of winter, thoughts are turning to the breeding season to come. Britain's only endemic bird species, the Scottish crossbill, often starts nesting when there's still thick snow on the ground, building its home in the highest branches of a Scots pine. Meanwhile the mighty cock capercaillie, the largest denizen of these forests, begins his dramatic courtship display early in the New Year. The story of the Highlands winter is one not just of survival, but also of preparations for spring. ■

Sitting in the eastern Highlands, the Cairngorm Mountains are Britain's only example of Arctic-Alpine habitat, home to some of the country's highest and coldest peaks, including Ben Macdhui (1,309m) and Cairn Gorm (1,245m). This image shows the Ryvoan Pass, frozen in the depths of winter

PHOTOS BY

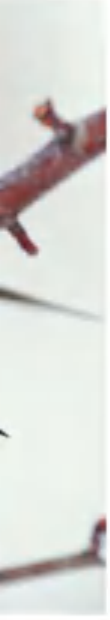
LAURIE CAMPBELL

Laurie has been photographing Scotland's wildlife for over 35 years, and regularly contributes to radio and TV programmes. His new book Scotland's Wild Heart features text by Stephen Moss.

THE LOCATION

THE SCOTTISH HIGHLANDS

The Highlands is usually defined as the area north and west of the geological feature known as the Highland Boundary Fault, which cuts a swath across the middle of Scotland from the south-west to the north-east. This is a stark land of mountains, wooded valleys, peaty rivers and rocky coasts, with a climate characterised by heavy winter snowfalls.



FAR LEFT A female Brambling perches on a sprig of hawthorn. This finch is the northern counterpart of the chaffinch. Though a handful of pairs breed in the Highlands each year, the vast majority of individuals seen here are winter refugees from Scandinavia and Arctic Russia. They come to Scotland to gorge on beech mast, and are often spotted in the woods around Strathspey

LEFT The mountain hare is Britain's only truly Arctic mammal. It's a tough little creature, perfectly adapted to survive the harshest winters high on the Cairngorm plateau. Mountain hares moult into white coats to hide from predators on the exposed winter landscape – only their black ear tips are visible as they hunker by day in snow holes, emerging to feed at night

ABOVE Barnacle geese descend on the Highlands in their thousands each autumn, after journeying from their breeding grounds in eastern Greenland and Spitsbergen, and gather in huge flocks to feed. This individual, photographed at Loch Indaal, Islay, is bathing to keep its plumage in tip-top condition

RIGHT Red squirrels do not hibernate in winter, relying instead on the caches of food they buried in the autumn. These little rodents choose specific and easy-to-remember sites for their winter larders, such as the base of a large oak tree. Several squirrels may use the same site, increasing their chances of finding a meal. This individual has successfully retrieved a hazelnut, which will provide a much-needed boost of energy

Grey seals are unusual among large mammals in that they give birth not during the spring or summer, but in late autumn. The female stays with her pup for three weeks, feeding it on fat and protein-rich milk, during which time it moults out of its white fur and into a sleek black coat. The mother then goes off to mate again, and the youngster is left to its own devices. Eventually, instinct drives it towards the sea and its new home

PREVIOUS SPREAD Well over half of the world's population of pink-footed geese passes through the Highlands each autumn. Many stop over temporarily to feed after their long journey from their northern breeding grounds, before heading further south. But thousands more spend the whole winter in Scotland, taking advantage of the plentiful supply of food

ABOVE The Ptarmigan surely deserves the title of Britain's toughest bird. This small, bantam-sized member of the grouse family spends its entire life on the high tops, changing plumage three times a year to blend effectively with the prevailing landscape. The Ptarmigan's adaptations to life in the freezer include feathered feet, which act as snowshoes when it walks across snow

RIGHT Snow can cloak the Highlands for weeks on end during the winter months, even in low-lying areas on or near the coast. The Lochans (here Loch nan Caor, North Harris) often remain ice-free, however

ABOVE The Golden eagle is one of the iconic species of the Scottish Highlands. These majestic birds are top predators but will also scavenge for much of their food in winter. This individual, photographed in Inverness-shire, is tucking into the carcass of a Red deer

LEFT This reindeer is part of a 150-strong feral herd introduced to the Highlands from Sweden in the 1950s. Her uber-thick, double-layered coat keeps her warm, and her broad hooves not only enable her to dig out lichen, but to spread her weight evenly on the soft snow, preventing her from sinking

ILLUSTRATOR: ANDY POTTS

RELATIVITY ON TRIAL

One hundred years ago, Albert Einstein wrote a groundbreaking theory that transformed physics forever. But are there any chinks in its armour? **Marcus Chown** delves deeper

At the height of WWI, in November 1915, German physicist Albert Einstein published a revolutionary theory of gravity. Not only did General Relativity show that Isaac Newton, arguably the greatest scientist to have ever lived, was wrong, it predicted black holes and that the Universe had been born in a Big Bang. It even showed, at least in principle, how to build a time machine.

The key thing Einstein recognised is that, in any small region of space, gravity and acceleration are the same thing. He came to this conclusion after considering Galileo's 17th-Century observation that all bodies, irrespective of their mass, fall at the same rate under gravity, hitting the ground at the same time if dropped from the same height. How could this be?

Einstein imagined a spacecraft far away from the Earth, which is accelerated at 1g. If an astronaut inside lets go of a feather and hammer from an identical height, the floor accelerates up towards them at 1g and both objects hit the floor at the same time. If the windows are blacked out and the astronaut doesn't know they are in space, they might conclude they are experiencing gravity on Earth.

Einstein deduced that we feel gravity because we are accelerating. We do not realise it – and this is the incredible part – because matter warps the four-dimensional space-time it sits in. There is a valley we cannot see in the space-time around Earth. Our 'natural' motion is to take the shortest path, or the path of least resistance, through space-time – that is, to fall to the bottom of the valley. The Earth's surface obstructs us, pushing back. This is how we experience gravity.

WHAT IS GENERAL RELATIVITY?

The General Theory of Relativity describes how mass and energy cause the fabric of space-time to warp, giving rise to what we perceive as gravity. This theory built on Albert Einstein's earlier Special Theory of Relativity. Both theories are based on the idea that the laws of physics act in the same way everywhere and that the speed of light is constant. From this starting point, Einstein deduced that as everything is moving relative to everything else, different viewers see the same event differently. This is where the theory gets its name.

The LISA Pathfinder mission will test the concept of a space-based gravitational wave detector

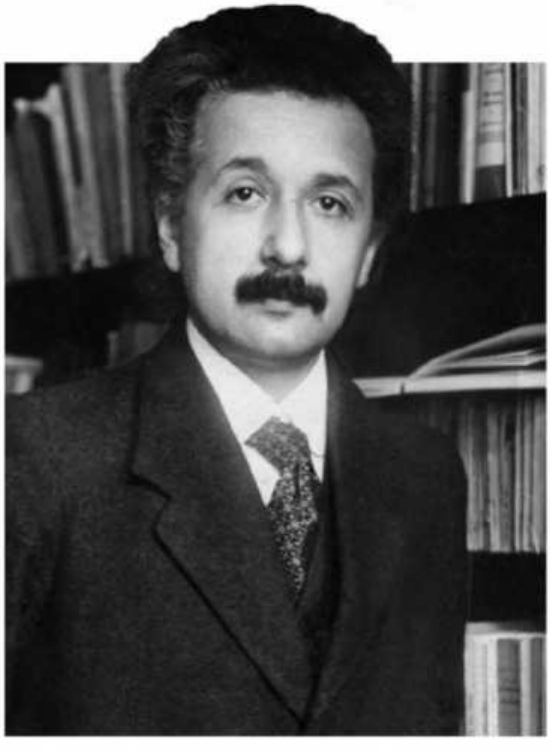
In a nutshell, this is General Relativity. As theoretical physicist John Archibald Wheeler said: "Matter tells space how to curve. And curved space tells matter how to move." The theory has passed every test in the past century, predicting and explaining phenomena beyond the scope of Newton's theory. But it is known to break down in the 'singularity' at the heart of a black hole and in the Big Bang. So physicists are searching for a flaw that points the way to a deeper, more fundamental concept that will fill in the gaps of Einstein's theory. One key prediction that has yet to be confirmed is the existence of gravitational waves...

Catching waves

Gravitational waves are ripples in the fabric of space-time, which spread outwards from an accelerated mass like ripples on a pond. The problem is that space-time is about a billion billion billion times stiffer than steel. This means it takes a lot to vibrate it and create gravitational waves. Only the most violent astrophysical events such as the birth or merger of black holes or the collision of super-dense stars are capable of causing vibration.

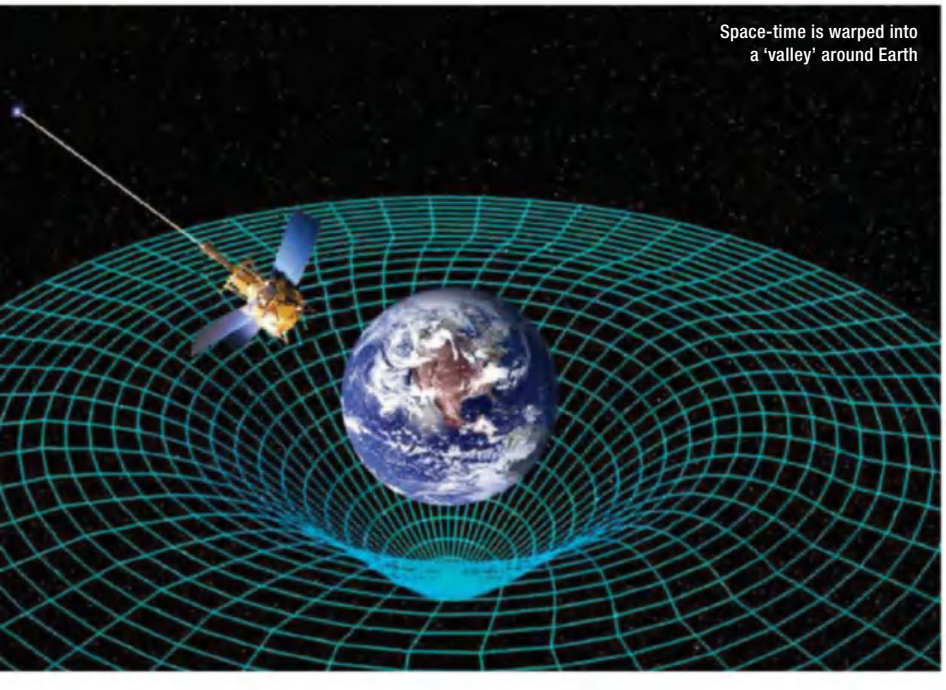
On 27 November this year, the European Space Agency (ESA) will launch LISA Pathfinder, a mission to test the concept of a space-based gravitational wave detector. The idea of LISA, which stands for Laser Interferometer Space Antenna, is to put a giant equilateral triangle in space, probably in 2034. The triangle will consist of three satellites, somewhere between one million and five million kilometres apart, bouncing laser light back and forth using mirrors. Think of the sides of the triangle as giant rulers. A passing gravitational wave is expected to alternately stretch space in one direction and squeeze it in a perpendicular direction, so the trick will be to look for subtle changes in the length of the rulers. "We expect to be able to detect change as small as the width of an atom over millions of kilometres," says LISA Pathfinder Project Scientist Paul McNamara.

Gravitational wave experiments have been built on Earth, but background vibrations of the ground mimic real sources, making them blind to the lowest frequency of gravitational waves. Such waves should be detectable by LISA. In addition, there should be a 'background' of tens of millions of events caused by white dwarf-white dwarf binaries in the Milky Way. 'Binaries' are systems consisting of two stars, orbiting a common centre of mass. "There is also a chance that a space-borne detector will be able to directly measure primordial gravitational waves produced in the first split-second of the Big Bang," says McNamara.



Left: Albert Einstein published his General Theory of Relativity in 1915 – the same year this image was taken

PHOTO: ESA, NASA, GETTY



Space-time is warped into a 'valley' around Earth

"Electromagnetic waves allow us to 'see' the Universe, whereas gravitational waves will allow us to 'hear' it," says McNamara. "Imagine going to an orchestra recital and only being able to watch the musicians without hearing any sound… now turn on the sound… this is what it will be like when we start to observe the Universe with gravitational waves." Prepare yourself for the cosmic symphony.

Going deeper

The fact that General Relativity breaks down in the 'singularity' of the Big Bang and a black hole, where the density of matter skyrockets to infinity, is not very helpful in trying to find a deeper, more fundamental theory. The hope is that General Relativity might reveal a chink in its armour in

The South Pole Telescope is part of a global array called the Event Horizon Telescope that aims to study the black hole at the Milky Way's centre

less extreme circumstances. This is the idea behind an Earth-orbiting experiment called Satellite Test of the Equivalence Principle, or STEP, which is seeking NASA funding. "If it gets the go ahead, it could fly in six years," says Paul Worden, one of the originators of STEP in 1971.

The 'Equivalence Principle' is the fancy name for gravity being indistinguishable from acceleration so that all masses fall at the same rate. Since the principle is the foundation of General Relativity, it is a key place to look for an anomaly. Galileo is supposed to have dropped different masses from the Leaning Tower of Pisa, and Apollo 15's Commander David Scott repeated the experiment – with a hammer and a feather – on the Moon in 1971. STEP will suspend four pairs of 'test masses' made of at least three different materials, such as beryllium, niobium and platinum-iridium, and see whether they move relative to each other.

"Electromagnetic waves allow us to 'see' the Universe, whereas gravitational waves will allow us to 'hear' it"

The masses will be inside a tank of liquid helium to insulate them from external temperature fluctuations and surrounded by a superconducting shell to shield them from electromagnetic interference. Microthrusters will counteract the atmospheric drag on the satellite, so the freefall of the test masses will be nearly perfect.

The key to the experiment is that a satellite in Earth orbit is always falling away from its desired straight-line path but never gets any closer to the Earth because the Earth's surface perpetually curves away from it. In other words, it is falling forever. This will enable small differences in the rate at which different masses fall to be magnified.

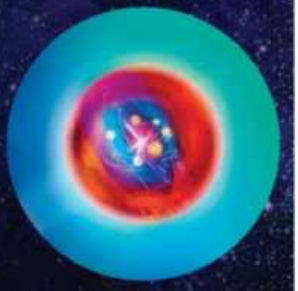
The Equivalence Principle is known to hold to one part in a trillion, but STEP will better that by another factor of a million. All attempts to unify General Relativity with quantum theory involve new forces, which may affect different materials in different ways. "A violation is basically the discovery of a new force of nature, or something really weird," says Worden. "If there's no violation, at least to experimental accuracy, we can rule out a lot of theories of gravity but not Einstein's."

5 WAYS

YOU CAN SEE EINSTEIN'S THEORY IN REAL LIFE

MASS

The 'Higgs field' accounts for only about 1 per cent of your mass. 99 per cent is due to a relativistic effect. Specifically, the quarks that compose you are moving so fast they gain mass. Without Einstein, you would weigh only about 1kg!



SUNLIGHT

According to Einstein, mass is a form of energy and so can be converted into other forms of energy. This is what is happening in the Sun's core, where nuclear reactions convert about 0.7 per cent of the mass of hydrogen nuclei into heat and, ultimately, sunlight.

GOLD

An atom absorbs and re-emits light when an electron moves between orbits. The light's energy (colour) depends on the energy difference between the orbits. Gold ought to appear silver, but its innermost electrons move so fast that they gain mass. This changes the light its atoms reflect, making it appear gold.

THE UNIVERSE

The distant Universe seen through telescopes is not actually there: it's an illusion. The reason is that matter creates valleys in space-time which light from distant objects must negotiate on its way to Earth. The Universe is therefore distorted as if seen through frosted glass.

SLUGGISH SATELLITES

If you have a smartphone or a sat-nav, it calculates your location relative to a constellation of Global Positioning satellites. When these swing in close to Earth, they experience stronger gravity and their on-board clocks slow. This effect must be compensated for to calculate your location.

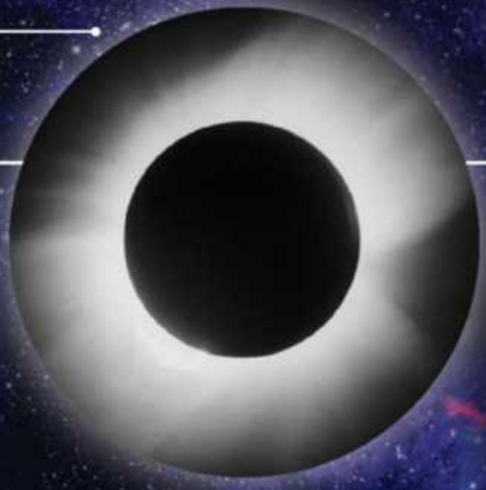
PHOTO: SCIENCE PHOTO LIBRARY, ISTOCK X3, NASA, DAN MARRONE/UNIVERSITY OF ARIZONA

GENERAL RELATIVITY'S SUCCESSES

THIS ISN'T THE FIRST TIME EINSTEIN'S FAMOUS THEORY HAS BEEN PUT TO THE TEST

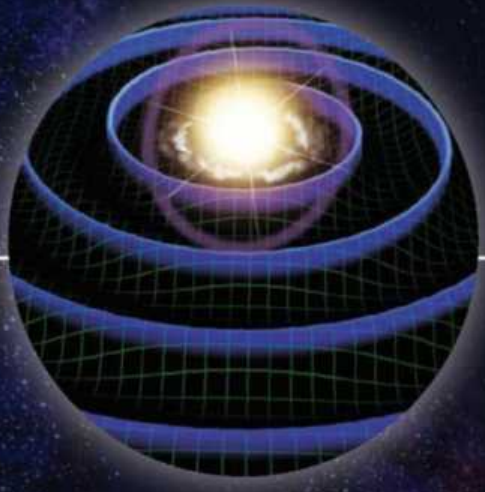
MERCURY MYSTERY

According to Einstein, the gravity near the Sun is stronger than Newton would have predicted. This causes the elliptical orbit of Mercury to gradually change its orientation. It 'precesses', which means the planet traces out a rosette-like pattern around the Sun. Before Einstein, this was such a puzzle that it led to the suggestion of a planet – Vulcan – tugging on Mercury.



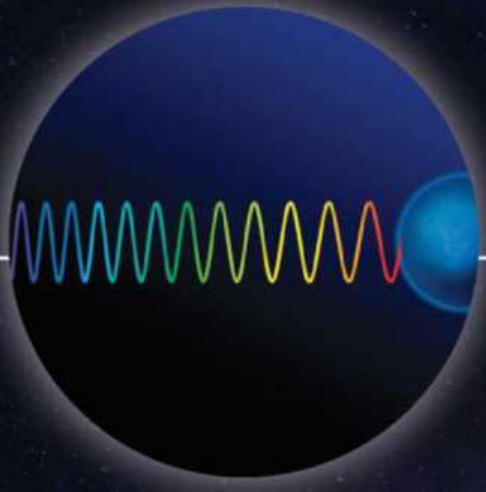
TIRED LIGHT

As light climbs out of the valley in space-time around a massive object like a star, it loses energy. This is equivalent to a reduction in its frequency and is known as a gravitational red shift. It has been observed in the light of dense, white dwarf stars. In 1959, it was even observed in light climbing up a 22.6m tower on Earth by physicists Robert Pound and Glen Rebka at Harvard University.



RIPPLING GRAVITY

Although gravitational waves have yet to be detected directly, they have been detected indirectly. In 1974, Russell Hulse and Joseph Taylor discovered two super-dense neutron stars orbiting each other. By observing the 'binary pulsar', or PSR B1913+16, they determined that the stars are spiralling together and losing orbital energy. This lost energy is exactly the amount Einstein's theory predicts they should be radiating into space as gravitational waves.



BENT LIGHT

Einstein calculated that the gravity of the Sun would bend the trajectory of light from distant stars by twice the amount Newton would have predicted. The only way to observe stars close to the Sun is during a total eclipse when the bright solar disc is blotted out by the Moon. During the total eclipse of 29 May 1919, the English astronomer Arthur Eddington confirmed that the positions of stars were shifted, exactly as Einstein had predicted.

Above: The Apollo 8 image of Earth taken from the Moon is pretty iconic – but a photo of a black hole event horizon could be even more impressive

The 'hole' story

But General Relativity might be put to its toughest test within only a year or two. So far, the theory has been checked only in situations where gravity is relatively weak. Nobody has tested it where gravity is strong – close to a black hole. That could all change when the Event Horizon Telescope (EHT) images the black hole at the centre of our Milky Way, probably in 2017.

The EHT is an array of cooperating radio telescopes scattered around the globe. The radio signals recorded at each site are flown together and combined on a computer at Haystack, Massachusetts to simulate a giant dish the size of the Earth. The bigger the dish and the shorter the observing wavelength – EHT is using 1.3mm – the more it can zoom in on details in the sky.

The trouble with black holes is they are very difficult to see. Stellar-mass ones are too small and the supermassive black holes in the cores of other galaxies, with up to 30 billion times the mass of the Sun, are too far away. Only one black hole is within reach – the one 26,000 light-years away at the centre of the Milky Way. Sagittarius A*, as it is called, will be magnified in size by its own intense gravity. "It will appear as big as a grapefruit on the Moon viewed from Earth," says EHT scientist Shep Doeleman of the Massachusetts Institute of Technology and leader of the EHT team.

"An image would be a turning point in our understanding of black holes and gravity"

The key thing is to observe the black hole's event horizon – the point of no-return for in-falling matter and light – and see whether it behaves as predicted by Einstein or even whether it exists. Stephen Hawking suggested it might not. This will test Einstein's theory in the realm of strong gravity, where it has never been tested before. "An image would allow us to test General Relativity at the black hole boundary but, just as importantly, it would make the case for the existence of black holes as solid as it is ever likely to be," says Doeleman. "An image would symbolise a turning point in our understanding of black holes and gravity."

Doeleman is being modest. It is possible that the first image of a black hole event horizon will be an iconic image to rival the Apollo 8 image of the Earth rising above the Moon.

In the world of science, 100 years is an awfully long time. Countless theories have been proposed since Einstein published his famous paper, with many of them turning out to be nonstarters or dead ends. After a century of extraordinary success, it still remains to be seen how far the General Theory of Relativity can be stretched before reaching its breaking point. Could its time be finally up? After all, even Einstein viewed the theory as being incomplete. If STEP, LISA or the EHT are able to find even the tiniest hole in its venerable armour, scientists could be on the brink of formulating a new theory of gravity, or maybe even making the first tentative steps towards the elusive 'theory of everything'. ■

MARCUS CHOWN is a science writer and author of *What A Wonderful World: Life, The Universe And Everything In A Nutshell*

PHOTO: NASA X2, SCIENCE PHOTO LIBRARY X2, GETTY

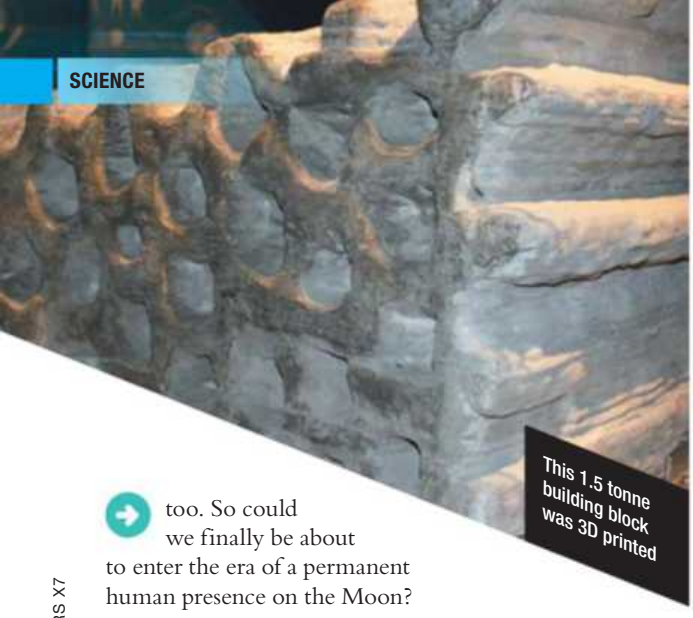
PHOTO: ESA/FOSTER & PARTNERS

CAN WE BUILD A BASE ON THE MOON?

ESA's new chief has suggested that a permanent "Moon station" could be a successor to the ISS. **Colin Stuart** takes a look at the current contenders for the first lunar outpost

"Now, let's get off. Forget the camera."

These ordinary words have an extraordinary significance: they are thought to be the last words spoken by a human being on the Moon. That was in December 1972, when the departing Apollo 17 mission brought down the curtain on three years of daring and audacious manned exploration during which 12 people left their historic footprints in the lunar dust. But for the past four decades our nearest neighbour has been without human contact, explored only by the robotic sentinels we've dispatched. But that may be about to change, at least if Johann-Dietrich Woerner, the new Director General of the European Space Agency (ESA), gets his way – he wants to build a village on the Moon. Other space agencies around the world, including NASA and the Russian agency, Roscosmos, have been making similar noises



This 1.5 tonne building block was 3D printed

too. So could we finally be about to enter the era of a permanent human presence on the Moon?

Stage 1: Getting There

First things first: the less you take with you the better. It costs at least $10,000 to launch just 1kg of material into space, and that's before you've even got it into lunar orbit and landed it on the Moon. "The big buzzword at the moment is 'in situ resource utilisation' or ISRU," says University of Leicester astrobiologist Lewis Dartnell. In other words, use what's already there as much as possible to keep the costs down. Therefore, local resources will govern where the base should be located.

MAKE A MOON BASE

1. The Moon's south pole gets light for 90 per cent of the day, making it the best location
2. The lander carries the habitation capsule to the Moon's surface
3. An inflatable dome released by the capsule provides a frame on which to build
4. Walls are 3D printed with lunar soil
5. Each section takes three months to complete

The 3D printer builds the base layer by layer

Woerner's idea is to start building on the far side of the Moon – the face that always points away from Earth. China also thinks this would be the best location. It would certainly be a good place to install telescopes, but the downside is that you'd need a system of relay satellites to maintain contact with Earth – a key psychological factor as it's important not to feel too cut off. Plus, if you're thinking purely in terms of resources, then close to the south pole of the Moon might be a better bet for an initial dwelling as there's plenty of water ice there as well as other minerals. The Russians are currently looking into the feasibility of a base at Malapert Mountain in this region.

The other upside to the south pole is the climate. The Moon is a very different place to the Earth, taking nearly a month to complete one rotation on its axis. So on most parts of the Moon, periods of day and night both last around two weeks. However, some regions of the Moon's south pole are almost always illuminated, much like the our North Pole in summer. This means there aren't huge changes in temperature, therefore allowing solar panels to soak up plenty of sunlight with which to power a potential lunar colony.

PHOTO: ESA, MONOLITE, FOSTER & PARTNERS X7

THE 3D PRINTER

1. The printing head builds up the structure layer by layer
2. Lunar soil is mixed with magnesium oxide to form printable material. It's 'set' with a binding salt to create a solid material
3. A scoop collects the lunar soil for use by the 3D printer

If at first a manned lunar colony seems like too much of a risk, we might start with a robot-only base.

That's certainly the plan that Jaxa, the Japanese Space Agency, has in the pipeline. It hopes to have a permanent robotic enclave on the Moon by 2020, with machines gathering lunar samples up to 97km (60 miles) away before returning to the base and blasting their haul back to Earth via rockets.

Stage 2: Building

The advent of 3D printing could be a game-changer. At the end of 2014, the design for a socket wrench was emailed to astronauts on the International Space Station (ISS), who then used their 3D printer to create it. Researchers are excited by the prospect of using a similar technique for bases on the Moon. ESA is already in consultation with architects Foster + Partners about the possibility of creating a large-scale infrastructure on the Moon by 3D printing it using

Moon base plan by Foster + Partners

LIFE INSIDE THE MOON BASE

1. A 3D printed shield protects from radiation and debris
2. The pressurised living area can house four people
3. Skylights provide the Moon base with daylight
4. The original capsule acts as an airlock and tech support module, with communication and equipment

PHOTO: ESA/FOSTER & PARTNERS, NASA

lunar soil as the raw material. "We've already demonstrated that 3D printing can be a very efficient tool and that it is possible to process lunar regolith [loose material]," says Laurent Pambaguian, Materials Technology Engineer at ESA.

It remains to be seen how the regolith would be collected in sufficient quantities and delivered to the printer, and Pambaguian warns of the need for an initial robotic mission to ensure the system works in the Moon's reduced gravitational field. But should it be successful, in an emergency a key piece of equipment could be designed, transmitted to the Moon and printed within hours – much faster than the days it would take to dispatch it by rocket.

In the concept by Foster + Partners, material would be 3D printed onto a light, inflatable scaffold. However, Bigelow Aerospace proposes the use of a small standalone inflatable pod and is already cooperating with NASA. Their first inflatable Moon bases will be in place by 2025, they say. The Russian plan to colonise Malapert Mountain is also being led by a private company – Lin Industrial. It believes the technology required for such a feat

A 1993 Moon base graphic from NASA

MOON FACTS

1.6M/S²
THE MOON'S ACCELERATION DUE TO GRAVITY

3,474.8KM
IS THE DIAMETER OF THE MOON

-53°C IS THE AVERAGE TEMPERATURE AT THE MOON'S EQUATOR

12
HUMAN VISITORS HAVE BEEN TO THE LUNAR SURFACE

3.8CM
THE DISTANCE THE MOON MOVES AWAY FROM EARTH EVERY YEAR

59%
OF THE LUNAR SURFACE CAN BE SEEN FROM EARTH

4.53 BILLION YEARS OLD

5TH
LARGEST MOON IN THE SOLAR SYSTEM

isn't available now, but predicts it will be in as little as five years. A total of 50 rocket launches would make the base a reality, but at a cost of nearly $10bn.

Stage 3: Living There

When it comes to our fragile frames, the Moon presents a number of biological problems. Humans evolved to live on Earth, not a barren lump of rock 402,336km (250,000 miles) away. We'd need to test out the effects of altered gravity on our biology too. "Zero gravity is totally devastating to the human body in terms of muscle wastage and the demineralisation of the skeleton," says Dartnell. On the Moon, the gravity is only one-sixth of what we're used to. "We don't know if that's strong enough for the human body to remain healthy," he adds.

Another key challenge colonisers will face is radiation. The Earth has an atmosphere and a magnetic field, both of which act as giant safety blankets protecting us from solar particles and cosmic rays from the Galaxy at large. With no natural protection from these dangers on the Moon, we'll have to find a way to shield ourselves. Otherwise radiation will penetrate the astronauts' skin and dump its energy into their DNA, leading to radiation sickness, cataracts and a much higher risk of cancer.

The radiation shield would need to be a couple of metres thick. "You'll need some form of lunar JCB, which you'd use to bury your habitat in material from the lunar regolith," says Dartnell, sticking to the ISRU mantra. That's enough to soak up the radiation before it reaches those living inside. The other essentials are water, oxygen and food. Luckily, the water ice present on parts of the Moon can supply the first two through melting the ice and splitting the H_2O up to get at the oxygen. Food will likely come from indoor greenhouses growing fresh fruit and vegetables, something Dartnell believes will have importance beyond simple sustenance.

"With Antarctica, even really simple things like growing tomatoes have been shown to be enormously beneficial for keeping people sane," he says.

That psychological angle shouldn't be forgotten. The first inhabitants of a lunar colony are likely to be very small in number – the Russians, for example, plan to start with two people before boosting it to four. Working in a pressurised, cramped and alien environment takes its toll on the psyche. Lessons can be learnt from previous experiments, like the trips to the ISS and the Mars500 project, in which volunteers were locked away in isolation to recreate a potential trip to the Red Planet.

What we can learn

The scientific attraction is clear. The lunar samples returned to Earth by the Apollo astronauts have been an invaluable resource in understanding the inner workings and history of our celestial companion. Yet that knowledge is still limited, as only a small amount of material was returned from a few lunar locations. A team of permanent dwellers would send our ability to study the Moon into overdrive. "A good comparison is how a permanent human infrastructure in Antarctica has facilitated scientific research that wouldn't have happened if we just parachuted in automatic payloads from time-to-time," explains Ian Crawford, a planetary scientist from Birkbeck, the University of London.

Interestingly, lunar habitation could extend our knowledge of areas far beyond the Solar System – the Moon has long been regarded as an excellent place to build telescopes to peer out into the distant cosmos. Optical telescopes would have an unprecedented view of the centre of our Milky Way and radio telescopes would be free from the ever-increasing background hum of modern civilisation. Humans could be sent to build and service this suite of instruments, much as they do with the mountain-top telescopes on Earth.

With so many untapped resources, the first Moon base may not be funded by government-led space agencies at all – private enterprise could be first to set up shop. A recent NASA study suggested that a public-private partnership could slash the cost of the mission by 90 per cent.

With eyes also on a permanent Mars colony, the Moon would be an excellent place to test out nascent technologies. It's certainly a lot safer – if things go wrong it only takes a few days to head for Earth's safety. Alternatively, emergency supplies could be couriered quickly to the lunar surface. An outpost on Mars would be far more remote, leaving anyone in a colony there at least six months from help. ■

COLIN STUART is an astronomy writer and co-author of *The Big Questions in Science.* He tweets from @skyponderer

ILLUSTRATOR: MAGIC TORCH

YOUR FIRST DAY ON THE MOON

So it's your first day on the lunar surface? Welcome to Clavius Base! Leave your stuff in the loading bay for now and let sci-fi author **Stephen Baxter** show you around

"I've got two pieces of advice straight away. The first is: watch your head! Were you expecting Dr Evil's lunar lair – Austin Powers, you know? – with glass domes and colour-coded uniforms? Well, forget it. As you can see it's small and cramped in here, with every surface cluttered up with equipment, or personal stuff where there's room. This is where you can sign up for the EVA soccer, by the way. Every cubic metre of living space has to be built, kept filled with renewed air and shielded from radiation. Yeah, it is kind of like the ISS. We're a space station located on the ground.

"And the second bit of advice: don't worry about the smell of burning. That's Moon dust oxidising in the air – super-fine grains that get in through the locks and filters no matter what we try. It's corrosive as hell on seals and membranes, and gets in the pores of your skin. You get used to it.

"Okay, here's where you'll probably spend most of your waking life: the health centre. This entire base is a kind of experiment; we don't know how human bodies will respond to lunar gravity and so we're the lab rats who are going to provide the data. Hope you don't mind needles! I see you have a red centrifuge badge – lucky you! I'm blue, as you can see; I have to spend a couple of hours a day spun up to Earth gravity. The grey-badgers don't get to spin at all, so they get nothing but lunar gravity pulling on their bones. But you red-badgers get spun gently at one-third G, which is the same as Martian gravity. Experiments in partial gravity can't be run on Earth, if you think about it.

"What's behind that blue door…? Don't worry, I'll tell you later.

"So here's one of our airlocks and a window looking out. Black sky, the ground a kind of tan colour. And the shape you see on the horizon is a robot miner, dredging the regolith for rare isotopes – fusion fuel for the Earth. That angular oil-rig-like creation is laying down solar-cell panels; most of our energy on the base comes from the Sun. Whatever your role you'll get to spend plenty of time out there – heck, you'd soon go stir crazy if not. We maintain the equipment, which isn't yet smart enough to do that for itself; we also play sports and go exploring. I'm signed up for a jaunt to the Moon's south pole next year. Maybe you'll come along.

"The view might not look like much. This is farside, of course, so during the lunar day there's only the Sun in the sky. But at night… wow, you get the sky of deep space. Buzz Aldrin, the second man on the Moon, said that the Milky Way must be full of small, rocky worlds like this, and if we can learn to live here we can live anywhere. And wherever we go, people will have skies like that. Makes you think, doesn't it?

"Okay, what we have here is the hydroponics bay. People spend a lot of their time in here – there's just something about the green, growing things, I guess. Bonsai is a popular hobby. And then there's life support, and the stores, and the dormitories, and now we're back by the main loading bay where we started out. It's not so big, is it? But you soon get used to it.

"And we may need more room soon. Let's go back to the medical bay and that blue door… Shh. Listen.

"That sound, my friend, is something new to the Moon after four billion years, and something entirely new for mankind. We're all kind of proud. And it proves we're here to stay. Yes, it's a baby's cry."

GENE CLUB

Scan this QR Code for the audio reader

London's Hackspace lab looks pretty innocuous from the outside…

PHOTO: JV CHAMARY

Amateurs are altering DNA as a hobby. So who are they, and what are they up to? JV Chamary meets the biohackers...

Within a tiny room in a north London basement, Ilya Levantis opens a tupperware containing what looks like a leftover takeaway. "Fashion designers these days get interested in this stuff," he says, proudly showing off a rubbery pancake in a brown liquid.

The "stuff" is kombucha, which is used to make fermented tea. It's produced by a colony of microbes, the most important being *Gluconacetobacter*, which secretes strands of cellulose. Unlike material made by plants, a kombucha pancake is almost pure cellulose. When thin, it can be dried for paper, and used in wound dressings and high-end speaker cones. When thick, it's tough enough for clothing. "Some people call it vegan leather," says Levantis, a 25-year-old graduate who works in bioinformatics. He can now do genetic engineering as a hobby.

Levantis is director of Biohackspace, a laboratory that's half the size of a garage in the London Hackspace – a building located, aptly enough, in Hackney. Some of the lab's equipment was built using tools from the nearby electronics, woodwork and metalwork workshops, while other kit was donated by universities. Biohackspace contains a PCR (polymerase chain reaction) machine that's used for amplifying DNA samples, shelves of chemical reagents and a fridge full of Petri dishes – all the things you'll find in a typical molecular biology laboratory.

> "THE FIRST THING I SAID WAS, 'I WANT TO PLAY AROUND WITH DNA AND STUFF'"

Except the lab doesn't cater for professionals, but amateurs. In March this year the UK Health and Safety Executive (HSE) registered Biohackspace as 'GM Centre 3266' – the first lab in the country that allows *anyone* to try their hand at genetic engineering.

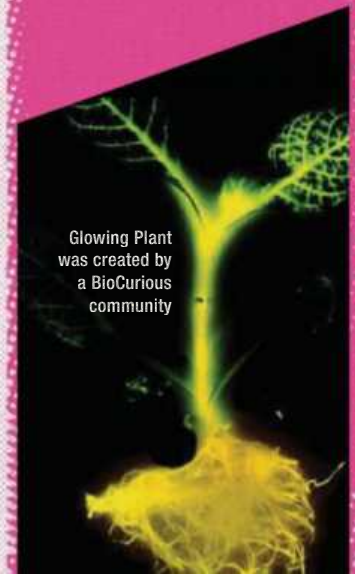
Although many of us think 'hacker' means a person who breaks things (technically, that's a 'cracker'), the word more properly applies to people who make or repurpose things, especially those who tinker with technology. 'Biohackers' play with biotechnology and form part of the Do-It-Yourself biology movement.

DIY bio groups are run by volunteers, and members usually pay a monthly fee to cover the costs of facilities and supplies for a shared lab, which provides affordable access to anyone curious about biology. In 2010,

BIOCURIOUS

This enterprising hackspace is bringing DIY bio to Silicon Valley

Back in the early days of modern computing, mavericks like Steve Jobs, Steve Wozniak and Bill Gates developed operating systems in a garage. The entrepreneurial spirit of early Silicon Valley continues in one of the world's leading DIY bio groups: BioCurious, which is based in Sunnyvale, California. Since opening almost five years ago, BioCurious has welcomed everyone from entrepreneurs developing proof-of-concept products to high-school students working on their science fair projects. The group grows by two or three members every month, and currently includes anthropologists, physicists and software engineers. One BioCurious community project on bioluminescence was spun-out as Glowing Plant, which raised $485,000 on Kickstarter. Glowing Plant's former lead scientist, Dr Kyle Taylor, now runs a 'plant research group' at BioCurious, where 15 members work on half a dozen projects.



Glowing Plant was created by a BioCurious community

Prototype cell-washing machine (left) for removing salt so bacteria accept new DNA, and two bioreactors (right) for making biofuels etc

Before being dried, kombucha is a gooey, rubbery substance

Reagents used for growing cells include vinegar and seawater

there were only a handful of biohacking labs; according to diybio.org, there are now over 60 local groups around the world. While groups generally start as 'garage biology', others – like BioCurious in California – have become larger.

Britan's biohackers

London's Biohackspace currently has about 20 regular members from various backgrounds, ranging from artists to engineers. Most have no scientific training. Lena Asai, a design student at Goldsmiths, University of London, got interested after seeing biology-inspired art at a museum in her native Japan, where a scientist suggested she find a community lab. That led her to Biohackspace.

"They didn't know what to do with me in the beginning," explains Asai. "The first thing I said was, 'I want to play around with DNA and stuff'. Obviously I didn't know anything back then!" She has since attended a bootcamp at University College London (UCL) to learn basic genetic modification techniques. Her goal is to bring scientists and artists together. "We're not doing science just for fun," she says. "A communal lab is a great place where we should initiate collaboration."

One of Biohackspace's collaborations involves the kombucha pancakes grown by Levantis. The liquid has added vinegar – to lower the pH for acidic culture conditions – plus food in the form of sugar, which can come from fruit juice. The team at Biohackspace wants to use the kombucha in a 3D-printing project called 'JuicyPrint'. While many 3D printers squeeze melted resin from a tube, depositing layers that turn solid after exposure to UV, JuicyPrint would use bacteria genetically-engineered to only produce layers of cellulose when blue light is shone on them.

Another project is a 'DIY Beer Kit', which aims to draw attention to hacking by exploiting the trend for home brewing. The kit includes a pick-and-mix of yeast strains, each genetically modified to make molecules that offer weird and wonderful flavours. Biohackspace entered its DIY Brew Kit in the 2015 International Genetically

Spin-out company Bento Bio is developing this 'lab in-a-box'

Kombucha being grown in an incubator

Biohackspace director Ilya Levantis (far right) discussing future plans with artist Lena Asai (centre) and other lab members

Engineered Machine (iGEM) competition, where it won a Bronze medal.

DIY bio and iGEM are closely linked to synthetic biology, which involves building living machines from a set of standard parts – genetic Lego blocks called BioBricks. This requires a toolkit, and the most powerful new technique in molecular biology is the CRISPR-Cas9 system, known as 'CRISPR'.

CRISPRs (Clustered Regularly Interspaced Short Palindromic Repeats) are sequences of DNA letters, first discovered in *E. coli* in 1987. A decade later, researchers revealed that CRISPRs form part of an anti-viral defence system used by bacteria and other microbes: after a virus invades a cell, enzymes cut and paste bits of the viral genome between CRISPR sequences in the cell's DNA. This leaves a genetic memory for an RNA 'guide' that an enzyme called 'Cas9' uses to recognise and destroy viral DNA, should an invader return. In 2012, bioengineers showed that the RNA guide could be reprogrammed to target *any* DNA sequence.

Unlike most gene-editing techniques, CRISPR is revolutionary because the technology is precise. It's also quick, cheap and easy to use – so simple that even amateurs can use it. Johan Sosa, an IT consultant and member of hacking group BioCurious, is already experimenting. "Currently we're creating the guide RNA to use for editing a yeast genome," he says. One possible application is the 'Real Vegan Cheese' project, which aims to modify baker's yeast so it produces milk proteins.

Playing safe

Anyone who tinkers with nature can be accused of 'playing God'. And given that some people are wary of genetic modification by professional scientists, it's understandable that some might worry about amateurs meddling with organisms they don't understand.

But even with CRISPR, we shouldn't overestimate what biohackers are capable of. "CRISPR is merely a tool – you still have to have an idea of what genes you want to turn on and off," explains Dr Darren Nesbeth, a

CRISPR

This powerful DNA editing technique is easy and quick – no PhD required!

1.

Scientists design a 'CRISPR' made from RNA. It includes a series of letters that matches a unique DNA sequence within an organism's genome.

2.

The CRISPR molecule is attached to 'Cas9' (shown here in beige). This is an enzyme that uses its RNA 'guide' to recognise the target DNA sequence.

3.

The CRISPR-Cas9 tool cuts the strands of the target DNA's double helix, then the cell's repair machinery will fix the damage – minus the old DNA sequence.

4.

The CRISPR technique can be used to delete unwanted DNA, or to find and replace a sequence by adding genetic material – such as a new gene.

PHOTO: ISTOCK X2, JAMES SMITH/THE GURDON INSTITUTE, GETTY

A thin sheet of dried kombucha produces strong paper

synthetic biologist at UCL. "Knowledge itself is the biggest barrier to being able to redesign a cell."

Biohacking is also limited by the resources available to a typical DIY bio lab. Reagents such as enzymes can be expensive, and companies that manufacture CRISPR sequences have safeguards to ensure they don't supply potentially malicious genetic material. "Somebody can't order the sequence to build the Ebola virus," says Maria Chavez, Director of Community at BioCurious. "Nobody is going to sell you those genes."

Objections to biohacking are similar to arguments in the GM debate, which discuss hypothetical scenarios such as strains escaping, or terrorists designing weapons. Nonetheless, DIY bio groups take it seriously. US government agencies like the FBI and Department of Defense keep in touch and send agents to visit labs. "At the beginning they were coming through quite frequently – at least once a month, formally," says Chavez. "Informally, I'm not sure how many times they may have dropped in."

DIY bio groups also have rules for what their members can work with. BioCurious labs are classified at biohazard safety level-1 (BSL-1), which means no projects using mammalian cells. At Biohackspace, no pathogens are allowed. "They've got a licence now from the HSE to do genetic modification, which requires they have a safety panel of individuals," says Nesbeth, one of the group's advisers. "There's a framework and guidance there equivalent to what happens at a university."

Citzen science

Research has traditionally followed two routes – academic and industrial – but hobbyists could provide a third way. Such citizen science involves freedom from responsibilities such as teaching and writing scientific papers. It also offers a nice environment for brainstorming, but such blue-sky thinking is less tethered in reality, says Nesbeth. At Biohackspace meetings, he tries to bring members back down to Earth without being too negative. "So you have to avoid just being there to be a party-pooper and saying, 'Well, this will take millions of pounds,' or 'Actually, that will take 10 years'."

Nesbeth supervises UCL's iGEM teams and studies industrial applications for synthetic cells, such as manufacturing drugs and biofuels. He believes the biggest impact could be on altering the perception that genetic engineering is only done by academics in an ivory tower. "I see it as a route to demystifying science for the general public," he says. Anyone can sign up to join their local biohacking lab.

At the end of Biohackspace's weekly Wednesday night meeting, several members take away sandwich bags containing kombucha to grow at home. Levantis mentions that because more people are getting involved in DIY bio, the lab now needs to expand beyond a basement in Hackney, a location which also makes it seem a bit hipster-ish.

"It's literally underground," Levantis jokes. "Our goal for the next lab is to have windows." ■

JV CHAMARY is a biologist and a writer. His latest book is *50 Biology Ideas You Really Need To Know*

A DOG'S-EYE VIEW OF PARIS

Parisian dogs have hunted criminals, been eaten as a delicacy with peas, and filled the streets with poo. Chris Pearson, who has been researching the history of dogs in cities, traces their impact on the French capital over the past 200 years

An attendant and his guard dog at the world's first pet cemetery, Paris, c1900. The cemetery was evidence, says Chris Pearson, "that pet dogs were now treated as part of the family"

AKG-IMAGES

BITING

Mad dogs and paranoid Frenchmen

Dog bites alarmed many Parisians, as fears of rabies stalked the 19th-century city. Rabies anxieties led some doctors, vets and other commentators to call for the eradication of dogs from French cities. Among them was army officer Alexandre Roger, writing in 1813, who lamented how rabies could strike anyone, rich or poor.

To minimise the risk of rabid dog bites, the police prescribed the muzzling of dogs in public places and targeted unmuzzled dogs for destruction. But the muzzling orders were often ignored and poorly enforced, while some doctors and vets labelled them dangerous because 'spontaneous rabies' was more likely to develop in restrained and repressed dogs. Animal protectionists, for their part, portrayed muzzles as cruel and ineffectual.

The French chemist Louis Pasteur's development of a rabies treatment in the mid-1880s did not eradicate fears of dog bites: the press reaction to Paris's newly minted police dog unit in the early 20th century dwelled on the possibility that police dogs might bite innocent Parisians, even if the dogs spent much of their time muzzled. More recent fears over dangerous dogs suggest that dog bites remain a source of concern and controversy.

CRIME-FIGHTING

Four-legged agents of the law

At the dawn of the 20th century, fear of crime in Paris was soaring. Lurid newspaper articles routinely portrayed the city as a wild, dangerous place, where violent street-gangs (so-called 'Apaches') preyed on hapless citizens.

The police needed to fight back – and fast – and so enlisted the services of Paris's pooches. Drawing on the experience of police dog units in Belgium and Germany, French law-enforcers started to train dogs to identify criminals and defend themselves against Apaches.

Scientists and philosophers had long posed the question: are dogs intelligent? For the police, the answer was a definitive 'yes', and they promoted their dogs' mental dexterity and physical prowess at dog shows, and many newspapers enthusiastically reported on the exploits of the "four-legged agents of the law".

Such was these canines' apparent success that Apache gangs reportedly trained their own dogs to attack the police's hounds. But doubts soon began to emerge about dogs' intelligence: could they really distinguish between criminals and innocent citizens? With such concerns rising, the attempt to turn dogs into canine crime-fighters floundered during the First World War and was only resurrected in earnest in 1965.

EATING

"Dog cutlets with petits pois"

During the 1871 Prussian siege of Paris, hungry and wealthy Parisians famously devoured the contents of the city's zoo, as well as cats, rats and dogs. Adolphe Michel, editor of the daily newspaper Le Siècle, attended a dinner where "dog cutlets with petits pois" and "brochettes of dog liver" appeared on the menu. The dog cutlets were over-marinated, he concluded, but the brochettes were "tender and completely agreeable".

We don't know for sure exactly how much dog meat humans actually ate – and reports of their consumption have undoubtedly been exaggerated.

In any case, modern Parisians have paid far more attention to what dogs eat, rather than what they taste like. As far back as the 19th century, public hygienists were praising stray dogs' proclivity for scavenging harmful debris from the streets – including infected carcasses covered in flies – so doing their bit to keep the city clean.

Since then, countless owners have tried to give their dogs a more refined diet. Just like their British and American counterparts, French vets have long advised dog-owners to provide their pets with a balanced diet of bread, vegetables and meat. And, by the late 19th century, they were were being bombarded by adverts for Spratt's dog biscuits, a mixture of processed flour, vegetables and meat powder.

DEFECATION

The dirty war on dog poo

The streets of Paris are infamous for being littered with dog mess. But canine excrement only emerged as a public health problem in the 20th century, after human and other animal wastes had been largely removed from the streets.

In the 1920s doctors and city councillors became alarmed at the diverse range of dog excrement splattered across Parisian pavements, which harboured harmful microbes and tapeworms. But reluctant to confront dog owners, the city authorities did little to tackle the problem until the election of Jacques Chirac as mayor in the late 1970s. With the number of Parisian dogs seemingly reaching breaking point, Chirac's administration launched educational campaigns, constructed dog toilets and brought the infamous 'moto-crottes' onto the streets of Paris. Adapted to 'scoop the poop', these motorbikes and their riders scoured the streets to much press and public ridicule.

But this technological fix was not enough to remove the estimated 20 tonnes of dog excrement deposited daily on the capital's streets. It was not until the enforcement of fouling fines in 2002 that progress was made. Yet dog poo remains on Parisian streets and continues to spark public health concerns, attract the ridicule of foreign observers, and provide evidence, for some, of widespread incivility in the capital.

An elegant Parisian with her pooch at the Bois de Boulogne in c1910–12. Walking dogs is a way of life in the French capital, yet strays have caused widespread fear and revulsion

WALKING

The curse of the canine vagabond

Owners walking their dogs are a ubiquitous presence in Paris. Such is the importance accorded to 'walkies' that busy Parisians can now pay for someone to walk their dog in Fontainebleau Forest (40 miles south-east of the city) while they are at the office.

Yet the authorities haven't always been so relaxed about the movement of dogs across the city. In the 18th century, "merchants, artisans and others" were banned "from letting their dogs loose on the streets at day or night". This legislation became even more stringent in the 19th century, when stray dogs were widely reviled for undermining the myth that dogs' main role was to serve humans as loyal companions.

Strays symbolised disorder – observers criticised their fondness for public fornication – in the supposedly modern city and, like human 'vagabonds', were treated as a threat to the rest of the population.

DYING

From pet cemeteries to industrial slaughter

Attitudes towards dead dogs lay bare the contradictions in man's relationship with canines in modern Paris.

The pet dogs of wealthy Parisians could be buried as if they were human – in 1899 feminist writer Marguerite Durand and lawyer Georges Harmois opened the world's first pet cemetery at Asnières-sur-Seine on the outskirts of Paris. Here, the headstones attest to the sense of loss that pet owners felt towards their departed canine companions.

The cemetery was a shrine to middle-class sentimentality, and evidence that pet dogs were now treated as part of the family. But it was also an attempt to make the capital more hygienic and prevent owners from throwing their dead pets into the river Seine, from which thousands of canine corpses were fished out each year.

At the same time, the municipal pound killed thousands of stray dogs in its lethal chamber, selling the bodies to renderers and glue makers.

Dr Chris Pearson is a lecturer in 20th-century history at the University of Liverpool, specialising in environmental, animal and French history

Into the Future

Staying healthy in space won't be easy for future Martians

Autumn saw the release of The Martian, in which a stranded astronaut must improvise everything needed for his own survival. Today, agencies like the European Space Agency have offices dedicated to space medicine, and the International Space Station is serving as a test-bed for medical techniques in space.

Before the first manned flights, there was speculation that humans might not be able to withstand space travel. In 1959, US psychiatrists theorised that a detachment from 'Mother Earth' might lead to suicidal 'separation anxiety'.

In fact, the first astronauts returned safely from their short hops into space. But longer missions, such as the two-week lunar journeys of the Apollo astronauts, revealed deeper dangers. Astronauts lose bone mass in zero gravity; in 2009, the calcium washed out of astronauts' bodies actually gummed up a urine recycler on the ISS. Sleep deficiency is common in an environment with no up or down, no night or day. Zero gravity even affects the shape of the human heart, causing it to become more spherical, which possibly causes problems with its efficiency.

And there have indeed been some psychological problems. During the American Skylab 4 mission, the crew got so mad at mission control that they cut radio contact for a day. Long periods of isolation and confinement must account for some of this, but there is some evidence that an altered blood flow in the brain can lead to an impairment of mental function.

Space explorers suffer different health problems to their Earth-bound friends

"An ISS astronaut could be returned to Earth within hours or days, but that option won't be available to a Mars-bound crew"

Deep space missions carry additional hazards. Earth's magnetic field shields people on the ground and in Earth-orbiting space stations from radiation from the Sun and more remote cosmic sources, but NASA estimates that a year-long flyby mission to Mars would expose astronauts to more than an acceptable lifetime dose of radiation. Solutions may include better shielding, medication and even the genetic treatment of the crew for radiation resistance.

Medical emergencies are a hazard in deep space. An ISS astronaut could be returned to Earth within hours or days, but that option won't be available to a Mars-bound crew. However, technologies enabling medical support in space are being developed. The May issue of Focus reported on a competition to design a 'tricorder', a tablet-sized device able to diagnose a range of conditions. Meanwhile, a lightweight MRI (magnetic resonance imaging) scanner is being developed for the ISS. As well as being able to detect problems such as incipient tumours, the scanners could be used to measure the astronauts' routine bone and muscle loss.

As for surgery, even if an experienced surgeon were available, the lack of gravity would complicate everything about a routine procedure. A Nebraska company called Virtual Incision is pioneering a miniature robot surgeon, which could be inserted inside the patient's body to perform quite complex surgery without the need for major incisions.

As a living environment, space has long-term health challenges. On the other hand, an old dream of space pioneers was that the cosmos may actually be good for you. In 1968, Arthur C Clarke outlined possible advantages of zero gravity for burns victims and patients undergoing post-operative therapy, and spoke of the wildly speculative possibility that life expectancy could be improved if gravity were removed. A retirement home in Earth's orbit? Sounds good to me. ■

STEPHEN BAXTER is a science fiction writer who has written over 40 books. His latest is *Ultima*, published by Orion

ILLUSTRATOR: ANDY POTTS

THE FUTURE OF GADGETS
TECHHUB

ON THE HORIZON

LYTRO IMMERGE

A camera for making virtual reality worlds

lytro.com

When Lytro launched its first Light Field camera back in 2012, enabling you to refocus pictures after they'd been taken, it was revolutionary – so much so that the rest of the camera industry has yet to catch up. But Lytro isn't resting on its laurels: it's now putting its Light Field technology to use in 3D motion picture capture for VR applications – a sector of the industry that's currently booming.

Where traditional photography records the colour and intensity of light at a given point (whether on a piece of film or a CCD sensor), Light Field or 'plenoptic' photography uses an array of lenses to capture much more information about the light in a given space, including its direction. Capturing so much data is what gives cameras such as Lytro's ILLUM the ability to change the focal point and depth of a picture after it's

The Lytro Immerge would capture the real world and translate it into a virtual replica

been taken. But all that additional information available about how photons are bouncing around also comes in handy for capturing 3D film footage in order to create virtual worlds.

That may seem like quite a niche application – and to a certain extent it is. No-one's suggesting that we're all going to rush out and buy Lytro's Immerge 3D video camera: it's strictly aimed at broadcasters, games production houses and other producers. But even they are being offered leasing options, because the Immerge system isn't cheap. Yet the fact that Lytro is investing so heavily in the sector underlines the increasing role that VR is likely to play in our lives.

Whether you're wearing dedicated hardware like Oculus Rift to play games, or using a smartphone-based solution like Google Cardboard to experience cutting-edge 'virtual journalism' (see, for instance, recent experiments by The New York Times), the fact is that after years of hyperbole, false starts and disappointment, virtual and augmented reality are soon going to be commonplace. This will create the impetus to find new ways to make the highest quality content – which is where Immerge comes in.

The Immerge system consists of a Light Field camera array and a portable server, plus a suite of editing and playback software. By capturing data from all directions, the camera enables the server and its firmware to generate virtual views from any point, facing in any direction. This, says Lytro, means content producers can create "a breakthrough sense of presence, with six degrees of freedom".

Lytro's Chief Product Officer Ariel Braunstein explains: "It's currently impossible to recreate multiple virtual views in a scene with a single capture from existing 2D video technology, which does not provide enough depth information. Many production houses are developing their own VR equipment and software simply out of necessity, in order to deliver their vision. We believe that Light Field technology solves many issues that face VR content creators right now.

"We believe that by helping to alleviate these pain points," he continues, "we will hopefully help VR storytellers create the kind of immersive experiences that will ultimately lead to wider consumption."

Light Field imaging isn't the only way to create immersive video, of course – there are almost as many ways to represent a cat from multiple viewpoints with realistic horizontal and vertical parallax as there are to skin one! But the arrival of the Lytro Immerge is another sign that the worlds around us – the real and the virtual ones – are about to get a whole lot closer. ■

RUSSELL DEEKS is a freelance science and technology journalist

PHOTO: GETTY X2

TECHOMETER

WHAT'S HOT

WAX CYLINDERS

Not the cylinders themselves – they were edged out by new-fangled 'records' around the time of WWI. Rather, it's the music stored on them that's making a comeback. A team at University of California, Santa Barbara has been busy digitising over 10,000 recordings from the 19th and 20th Centuries, which you can hear and download at cylinders.library.ucsb.edu

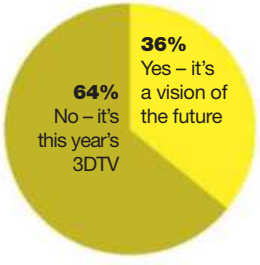
WHAT'S NOT

BETAMAX

Sony has announced that in March 2016, it will discontinue production of Betamax cassettes. Despite VHS emerging as the dominant video format by the mid-1980s, Sony carried on making Betamax equipment right up until 2002, and it's been quietly supplying users with new tape all this while. But March will see the format's 41-year run finally coming to an end.

READER POLL

Will virtual reality take the world by storm?



THE NEXT BIG THING

DIGITAL ARCHAEOLOGY

Are we becoming buried under mountains of data?

Google's data centres hold a lot of the world's data, but good luck sorting through it…

As part of my job, I get to give a lot of talks at conferences. I enjoy it a lot, partly because I like to meet new people, partly because it provides me with an opportunity to travel, but mostly because I've always found that the best way to test out your ideas is by saying them out loud in front of a bunch of sceptical listeners.

And I like to use my own photos when I can, because they make the whole thing a lot more real. In fact, I'm writing this in a cafe in Bern where I've been taking photos that I'll use in a talk today.

Unfortunately I can't find a photograph I'd really like to use, of some young people playing a PlayStation game in Nairobi's Kibera slum back in 2009. It should be somewhere in my photos, but it seems to have moved, and I never got round to tagging it or saving it with a sensible file name, so Spotlight can't find it. I have used it in other presentations, but I'm not sure which ones and it would mean trawling through a lot of files that I keep in the cloud these days because my laptop doesn't have much disk space.

This is a minor problem for me, but it's a growing one for our society as a whole. As each of us generates more and more digital data, spread across devices we own and a bewildering array of online services or cloud storage platforms, we're going to find it harder to connect with our memories. And we're going to leave our kids and ancestors with no real record of who we were or how we lived our lives.

Some media are better than others. With email and documents, a dumb text search will generally give you useful results. But all those recordings of interviews and talks I've saved might as well be deleted given how likely I am to transcribe or use them again.

There is an opportunity here. We're already seeing 'digital archaeology' emerge as an academic discipline, as we look to historians and biographers to make sense of the data detritus we leave behind. And there are new tools that will trawl your images, videos and sound files and do a half-decent job of tagging them, like Google Photos or the BBC's Comma toolset. Yet the nuances of classification seem likely to resist algorithmic interference for some time, if only because the range of reasons a person might want to find a specific item is effectively unlimited.

Once upon a time a wealthy person might have advertised for a 'corresponding secretary' to help deal with letters and invitations – perhaps there's a new career path emerging for the digitally-minded young people coding on the Raspberry Pi or eagerly awaiting the delivery of the first batch of BBC micro:bits to their school. Then they can help the older generation tag and organise their digital photographs, blogposts and Vines, and ensure that we don't end up bequeathing the world a pile of useless bits. ■

BILL THOMPSON contributes to news.bbc.co.uk and the BBC World Service

FROM THE LAB EM-SENSING

WHAT'S 'EM-SENSING'?

It's a new technology, developed by Disney and Carnegie Mellon University, that enables a wearable device to know what objects – for instance a keyboard or power tool – you're holding.

HOW DOES IT WORK?

All electrical or electromechanical objects emit small amounts of electromagnetic (EM) 'noise' that propagates harmlessly through your body when you touch them. These signals can be used to identify objects.

WHY IS IT USEFUL?

The idea is that a smartwatch or other wearable device with EM-sensing would know what you're doing and then feed you data that's specific to that task: local maps if you're driving, for example, or a timer if you're brushing your teeth. The system could also be used to log you into your computer without using a password.

SO WHEN'S IT HAPPENING?

Sadly there are no plans for actual products yet – the research is still at the 'proof of concept' stage.

Graphene ink could allow the cheap production of smart labels

PHOTO: GETTY, EMSENSE

Q&A

YOUR QUESTIONS ANSWERED

BY OUR EXPERT PANEL

SUSAN BLACKMORE

Susan is a visiting psychology professor at the University of Plymouth. Her books include *The Meme Machine*

DR ALASTAIR GUNN

Alastair is a radio astronomer at the Jodrell Bank Centre for Astrophysics at the University of Manchester

ROBERT MATTHEWS

After studying physics at Oxford, Robert became a science writer. He's a visiting reader in science at Aston University

GARETH MITCHELL

Starting out as a broadcast engineer, Gareth now writes and presents *Digital Planet* on the BBC World Service

LUIS VILLAZON

Luis has a BSc in computing and an MSc in zoology from Oxford. His works include *How Cows Reach The Ground*

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PHOTO: GETTY

Q How do waterfalls freeze?

A Water turns to ice when its molecules move slowly enough to form rigid bonds. Normally, the molecules in the waterfall move under the influence of both the flow and thermal agitation. But if it gets cold enough, the heat effect becomes so low that not even the waterfall's motion can stop ice forming, gradually at first but then ever more rapidly. **RM**

Perhaps if they all blow really hard, that will help too?

Can a yacht ever travel faster than the wind?

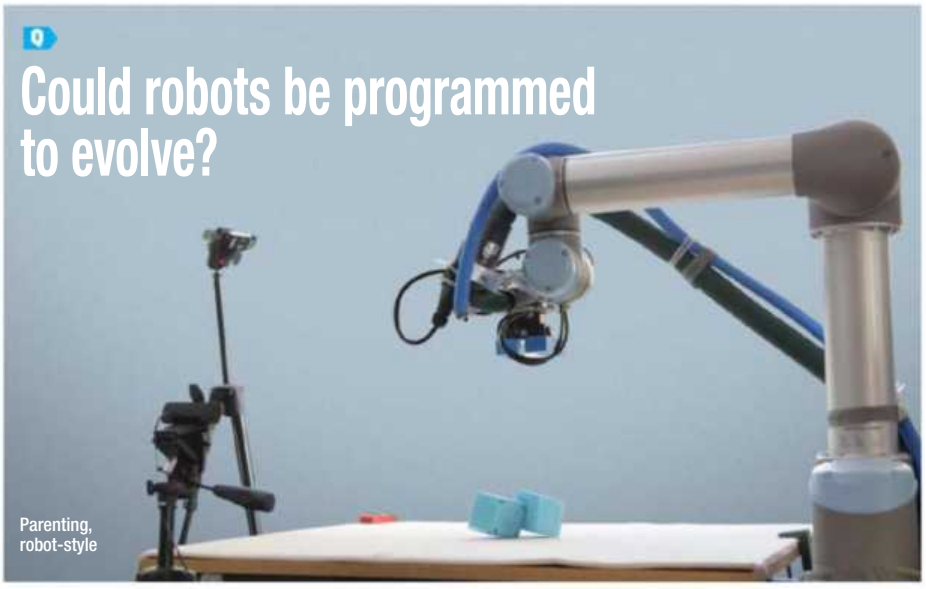
This seems like defiance of the laws of physics, but it just needs the right shape and size of sail to trap enough of the air-mass blowing in the wind. The resulting transfer of momentum can propel yachts to impressive speeds, especially if friction is minimised – some sleek catamarans can achieve 80km/h using 35km/h winds. **RM**

On average, how many of our muscles do we use regularly?

Just about all of them! But our least-used muscles are probably the lumbar multifidus muscles in the lower back. Studies have shown that prolonged slumping in front of the TV can inactivate these muscles. This can lead to back pain, and once inactivated they can take months to recover. **LV**

We're not convinced that a 5kg barbell gave him those biceps

Could robots be programmed to evolve?



Parenting, robot-style

Yes. In research that was published in August this year, teams in Cambridge and Zurich built robots that evolve through successive generations.

The 'mother' is a robotic arm that builds 'baby' robots out of small cubes. Each cube has a mechanism where one side can waggle. When you place it on a surface, it clumsily drags itself around. The mother glues these moveable cubes together in various arrangements. Some combinations move further and faster than others. The mother robot builds each arrangement using assembly instructions in the form of a 'genome' that is passed between successive generations of robots.

The mother is programmed to insert random mutations into each generation. Some offspring move around better than their forerunners, but others do worse. The mother rejects deficient generations but uses the genetic blueprints of successful ones to build subsequent offspring. In the lab, after only 10 generations, the robots performed twice as well as those at the start of the process. **GM**

Could we exist on Earth under a red giant star?

About five billion years from now, the Sun's usual source of nuclear energy will be depleted. It will begin to expand and cool significantly, becoming a 'red giant'. Its outer layers will be thrown off into space. As the Sun loses mass, its gravitational pull will weaken and the planets' orbits will widen. We know that Mercury and Venus will not be able to outrun the expanding Sun, and will be engulfed and incinerated.

Earth may just outrun the swelling red giant but its proximity, and the resulting rise in temperature, will probably destroy all life on Earth, and possibly the planet itself. However, there's no reason that life could not survive on another planet (or moon) sufficiently far out from the Sun, as long as it lies within the Sun's expanded 'habitable zone'. Life could also survive on suitably hospitable planets around other red giants. **AG**

The future's so bright, we're all going to die horribly in a stellar inferno

PHOTO: ALAMY, UNIVERSITY OF CAMBRIDGE, ISTOCK X2, GETTY, SCIENCE PHOTO LIBRARY

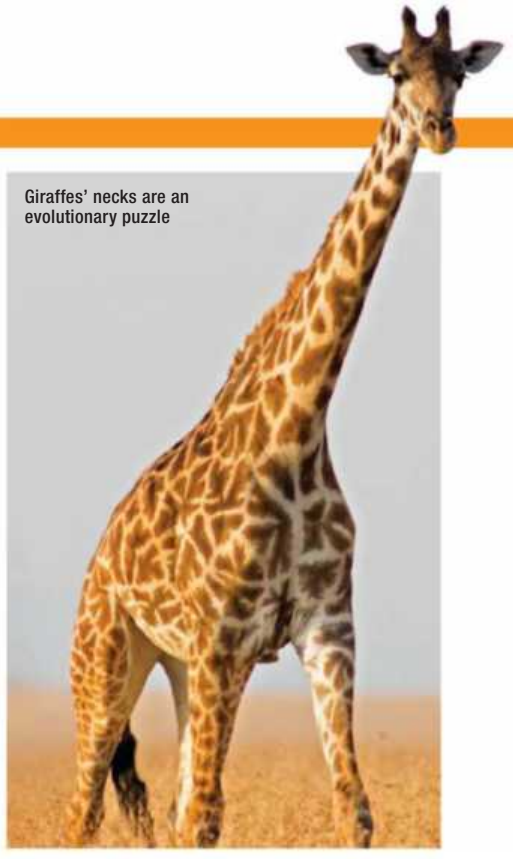
Q&A

Australian lead mines will leave a lasting impression on Earth's surface

If humans became extinct, how long would it take for all traces of us to vanish?

A Stonehenge is at least 4,000 years old and still visible today, and monuments buried nearby could be even older. Most modern buildings aren't that robust, but some traces would likely remain for at least 10,000 years, even if it was just the magnetic trace of the steel bars inside concrete blocks. When Hong Kong Airport was constructed in the 1990s, the island of Chek Lap Kok was flattened and extended, and the straight edge of its northern coastline will be a clue to our civilisation for tens of thousands of years. Our atmosphere also has high levels of plutonium-239 due to nuclear weapons testing during the Cold War. This isotope only occurs in nature in incredibly small amounts, and will be detectable as a pollutant for at least 250,000 years.

But the most enduring signs of civilisation will probably be deep mines in hard rock, such as South African gold mines and Australian lead mines. Here, visiting aliens would be able to see signs of our civilisation for millions of years, as the tunnels fill up with sediment washed down by rainwater to create massive industrial 'fossils'. **LV**



Giraffes' necks are an evolutionary puzzle

Aren't epigenetic effects evidence for Lamarckism?

A Not really. Epigenetics is when genes alter their activity in response to external factors such as diet, exercise and chemical exposure. The sequence of letters in the DNA doesn't change, but the DNA molecule acquires other chemical changes that can be passed on to your offspring. These inherited traits last for two or three generations.

Lamarckism says the giraffe got its long neck because parents stretched their own necks slightly during their lifetimes and passed that increase on to their children, and so on. That's quite different from the Darwinian view that each generation has a certain amount of natural variation, and that giraffes with longer necks have more offspring. Epigenetics is an important influence on evolution, but it doesn't drive long-term species change. **LV**

In Numbers

0.325mm

is the size of the world's tiniest free-living (non parasitic) insect – a featherwing beetle

TOP TEN
FASTEST FISH IN THE OCEAN

1. Black marlin
Maximum speed: 129km/h
Range: Australian coast and tropical Indo-Pacific

2. Sailfish
Maximum speed: 110km/h
Range: Indian and Pacific Oceans

3. Striped marlin
Maximum speed: 80km/h
Range: Tropical and temperate regions of Indo-Pacific Ocean

4. Wahoo
Maximum speed: 78km/h
Range: Tropical and sub-tropical waters around the world

5. Mako shark
Maximum speed: 74km/h
Range: Tropical to temperate waters worldwide

6. Atlantic bluefin tuna
Maximum speed: 70km/h
Range: Open waters of the Atlantic Ocean

7. Blue shark
Maximum speed: 69km/h
Range: Deep waters of temperate and tropical oceans

8. Bonefish
Maximum speed: 64km/h
Range: Shallow, inshore tropical waters

9. Swordfish
Maximum speed: 64km/h
Range: Tropical and temperate waters of the Atlantic and Indo-Pacific

10. Fourwing flying fish
Maximum speed: 56km/h
Range: Subtropical waters of the Atlantic and Pacific

Q

How do astronomers measure the size of planets?

A There are several ways that planetary diameters can be measured. The most common is to measure the apparent angular diameter of the planet – how big it looks against the sky – very precisely using a telescope. Combining this with a measure of its distance (deduced from its orbit around the Sun) reveals the planet's actual size. Another method involves studying the motion of moons as they eclipse the planet. Some accurate values of diameter, for example for Venus, come from radar observations from space probes in orbit. **AG**

Q

What was the life expectancy of a dinosaur?

A Scientists can measure the age of some dinosaur species from the growth rings inside fossil bones, much as you can tell the age of a tree by the rings inside its trunk. The oldest known Tyrannosaurus rex specimen, this method tells us, was 28 years old when she died, by which age she was fully grown.

But this technique doesn't work well on many species, because their bones grew continuously and don't have neat growth rings. Early estimates of 300-year lifespans for the largest sauropods were based on comparisons with crocodiles and turtles, which have much slower metabolisms. The consensus is now that Apatosaurus and Diplodocus dinosaurs probably only lived for 70 or 80 years, which is about the same as an elephant today. **LV**

Apatosaurus lived around 150 million years ago

PHOTO: ALAMY, GETTY X8, ISTOCK X3, REX, PRESS ASSOCIATION, SCIENCE PHOTO LIBRARY

Q&A

Why do people cheat?

Steroid use cost Ben Johnson his 1988 Olympic gold medal

A Because they want to win the easy way. As competitive animals, we human beings constantly seek out opportunities to gain money, food and sex, or simply to look good. Doing all this the hard way requires expediture of time, effort and energy, so cheating can obviously be very tempting.

Evolutionary game theory has helped to explain how altruism can exist alongside cheating. Generally, cheats do well when they are rare, but less well when they are many and have fewer non-cheaters they can exploit. So groups tend towards an equilibrium, with few enough cheats that it's not worth the cost of stopping them. Sadly, this basic biological principle means we are unlikely ever to be completely free of cheats. **SB**

How exactly does electricity kill you?

A At low currents, AC electricity can disrupt the nerve signals from the natural pacemaker in your heart and cause fibrillation. This is a rapid fluttering vibration, too weak to pump blood. If the rhythm isn't restarted with a defibrillator, it's usually fatal. At higher currents, DC electricity can have the same effect by causing the entire heart muscle to contract at once, which also breaks the pacemaker rhythm. The highest currents (more than one amp) cause burns through resistive heating as the current passes through the body. If this path crosses the heart or brain, then the burn may be fatal. **LV**

Is it true that dogs can detect cancers?

A Stories about dogs warning their owners of early signs of cancer have been circulating for years. Now hard scientific evidence is emerging to back the idea – at least for trained dogs. Studies involving dogs exposed to samples of breath, urine and other body fluids from cancer patients suggest they can detect the presence of lung, colorectal and prostate cancer, among others. In some cases, the dogs outperform standard lab tests, achieving higher detection rates and fewer false alarms.

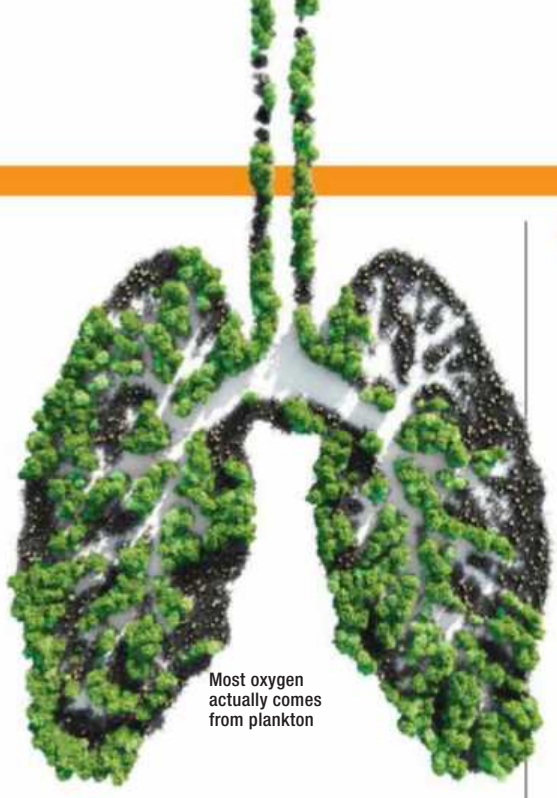
Researchers believe the dogs' highly refined sense of smell can detect the volatile organic compounds produced by malignant cells. However, a recent review of the evidence cautioned that it's still unclear whether the dogs can pick up signs of cancer early enough to be useful. More research is needed, and a major UK trial of the ability of dogs to detect breast cancer in breath samples from 1,500 women is currently underway. **RM**

Dogs have proven especially good at detecting tumours wrapped in bacon

What dictates where branches grow on a tree?

The hormone auxin controls how tree branches grow

A As the trunk grows upwards, buds are produced on either side. These buds are initially dormant because the growing tip at the top, called the 'apical meristem', produces the hormone auxin, which inhibits their development. Once the apical meristem has grown far enough away, the concentration of auxin near the bud drops and it can begin growing sideways. This sideways shoot also lays down its own buds, which are in turn kept dormant until the shoot's own growing tip has advanced enough. **LV**



Most oxygen actually comes from plankton

How does Earth maintain a constant level of oxygen?

It doesn't! The oxygen level of the planet has varied quite dramatically in the last 500 million years. It was 35 per cent during the Carboniferous period, around 300 million years ago; as the climate cooled and land plants died off, oxygen fell to as low as 12 per cent by the beginning of the Triassic. Back then, the air at sea level would have felt thinner than at the top of the Alps today.

Burning fossil fuels has reduced oxygen levels very slightly – about 0.057 per cent over the last 30 years. Deforestation only has a small effect because when rainforest is cut down, other plants are usually grown in its place. But it's marine plankton, rather than trees, that produces about 70 per cent of atmospheric oxygen. Global warming will have a significant impact on plankton, which is a much more serious threat to oxygen levels. **LV**

In Numbers

48 million

is the age in years of a 12.5cm-long fossilised foetus being studied in Germany. The specimen is thought to be an early horse-like species

Is crying good for you?

Many people would say yes. Crying is said to be cathartic, relieve stress and even remove toxins from the body, and most therapists claim it's beneficial. There is evidence that blood pressure and heart rate fall after crying, while some allergic reactions are reduced after watching weepy films, and sufferers from rheumatoid arthritis who cry have less pain than those who don't.

Yet the experimental evidence is mixed. Benefits are more likely when the reason for crying is a resolvable problem and the person crying is comfortable expressing their emotions and not otherwise depressed. One function of crying may be to show our distress, which can help build relationships, and this may be why crying helps. **SB**

Could an asteroid impact push the Moon closer to us?

The Moon is very big, and any small object hitting it would have very little effect on its motion around the Earth, because the Moon's own momentum would overwhelm that of the impact. Most asteroid collisions would result in large craters and little else; even the largest asteroid known, Ceres, wouldn't budge the Moon.

However, if an object of similar mass and velocity to the Moon were to hit it, the Moon's orbit could well be altered, though it's more likely the Moon would be destroyed by such an impact. If the Moon were to orbit closer to Earth we would experience much larger tides, along with longer and more frequent solar eclipses. **AG**

No satellites were harmed in the making of this picture

PHOTO: ISTOCK X2, SCIENCE PHOTO LIBRARY ILLUSTRATION: GRAPHIC NEWS

THE DRINKABLE BOOK

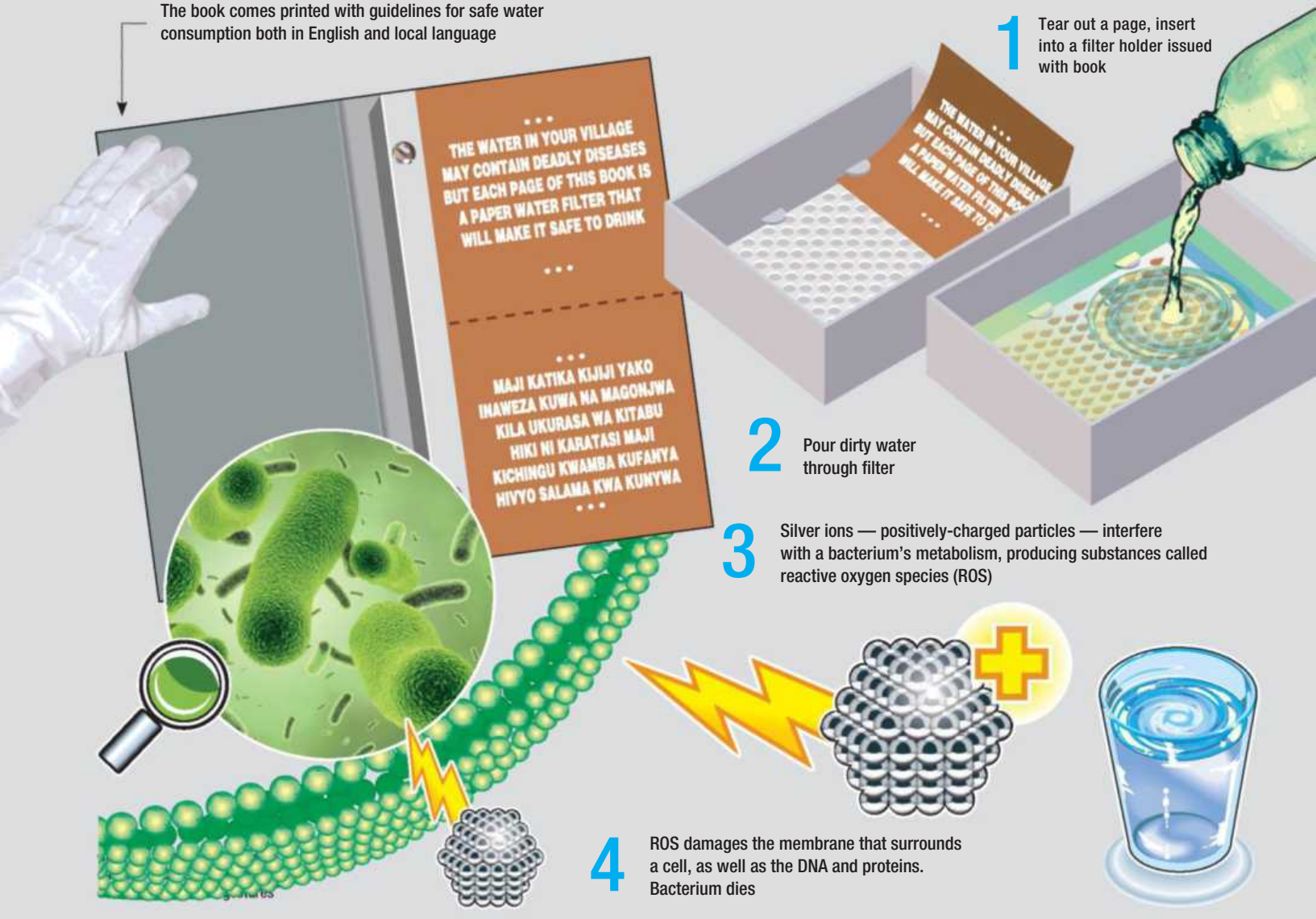
Every year, over 3.4 million people die from problems associated with water, hygiene and sanitation. It's a huge problem, because the vast majority of individuals who live in areas with dirty water don't even realise that it's unsafe to drink.

To try to solve the issue, Dr Theresa Dankovich created a special type of bacteria-destroying filter paper for her PhD at McGill University. She's now based at Carnegie Mellon and has teamed up with scientists from her current institution and the University of Virginia to create The Drinkable Book.

Once water has been passed through a page of the book, it comes out on the other side with a 99.9 per cent reduction in bacteria, which makes it comparable to tap water in the USA.

It works because each page is coated with silver nanoparticles, which are capable of destroying bacterial diseases such as E. coli, typhoid and cholera. Each filter can offer 30 days of clean water – up to 100 litres – and each book can last for up to four years.

The text printed on each page of the book helps educate people about water safety, by explaining the importance of keeping rubbish and human waste away from the water supply. So far, the filters have been trialled successfully in the developing world. However, at present, the papers are not capable of destroying other organisms, such as protozoa and viruses.



Why do bees die after stinging you?

A Honey bee stings have a barbed ratchet mechanism that pulls the stinger into the initial wound. This didn't evolve as a suicide mechanism – honey bees can pull their stings out after stinging other insects. It's meant to drive the stinger in as deep as possible; it just happens that mammal skin is too fibrous to release the sting, so the abdomen is torn open when the bee tries to escape afterwards. Honey bees are the only species to suffer this fate, but the cost to the hive of losing some workers is worth it for an improved ability to repel honey thieves. **LV**

This pollinating insect has passed on. He is no more. He has ceased to bee

Why do we have moles on our skin?

A During the first 12 weeks of pregnancy, the developing foetus is making melanocytes – the skin cells that produce ordinary skin colour. These aren't always evenly spread out: random areas will acquire a cluster and during your life, these clusters can grow into a mole.

Moles are quite different from freckles. Almost everyone has from 30 to 60 moles on their body, but freckles only occur in people with certain genes – particularly the one responsible for red hair. Freckles also need sunlight to trigger them, while moles appear spontaneously. **LV**

Why is it colder at the top of a mountain, if you're closer to the Sun?

A As the Sun is around 150 million kilometres away, even being on top of Everest only brings you 9km closer – far too small a difference to make you feel any warmer. The distance effect is totally overwhelmed by that of having less atmosphere around you as you climb. This leads to a steady fall in atmospheric pressure, and – as the air isn't so compressed – a fall in temperature as well.

The rate of decline is surprisingly fast: around 1°C for every 100m, and continues all the way up to the so-called tropopause around 12km above the Earth.

At these altitudes, barely 10 per cent of the atmosphere remains, and the air pressure is so low that the temperature falls to a lethally cold -55°C. The threat is not academic, either: at any given time, hundreds of thousands of people are being transported at these altitudes aboard aircraft. Passengers and crew are kept warm using hot air taken from the compressor stages of the engines before it's mixed with fuel. This, combined with insulation in the walls and heat generated by the passengers themselves, ensures the cabin can be kept at room temperature. **RM**

PHOTO: PRESS ASSOCIATION, ALAMY, ISTOCK X3, GETTY

Q&A

What makes people afraid of the dark?

Torches are an effective under-bed monster deterrent

A Loss of vision. Sight is our strongest sense and some of our natural predators, such as the big cats, had better night vision than our ancestors did. Our ancestors also had to watch out for enemy raids; even today, we may justifiably fear being burgled.

But our greatest fears come from our own minds. Many children, and some adults, are terrified of the monster under the bed. This is called the 'sense of presence' and is often associated with sleep paralysis, when you wake up unable to move. These monsters are due to unusual activity in areas of the brain. Then there are all those ideas that we don't like to face – our shame, guilt, anger, anxiety or whatever it may be. These seem far worse in the dark because our brains are deprived of the visual input that keeps them busy and suppresses those unwanted thoughts. **SB**

Why does time go so fast when you're asleep?

A Does it? Generally this is not true, and most people are good at judging how many hours they've slept. Some can even tell themselves to wake up at a specific time and do so. Time perception can be distorted, though, and experiments show that estimates are generally good, but people tend to overestimate time passed during the early hours of sleep and underestimate during the later hours. Time estimations during dreaming are much more variable and some people claim to have dreamt a whole lifetime in one dream. However, the best experiments to test this come from those very rare people who can induce lucid dreams (knowing they are dreaming) at will, and then signal to experimenters to indicate what they are doing in the dream. When asked to count to 100 while dreaming or while awake, the times taken match closely. And when asked to estimate how long a dream event took, those estimates are accurate. So if time does go fast when you are asleep, you are unusual! **SB**

Can computers make mistakes?

A Computers don't make mistakes, as such, but they can make errors. When your laptop crashes, it has gone into an error condition where it fails to run the computer code effectively. If anything, the 'mistake' is that of the human who produced ineffective code or faulty hardware. Or it's a simple case of the user asking the machine to perform a task that's outside its normal operational envelope. **GM**

Why do little girls like pink?

A Probably because of social pressure. In Britain and the USA, older girls like pink more than boys do, but they could already have been influenced by expectations. So studies have tested one- to two-year-olds by using the 'preferential looking task', which measures what the children like to look at the most. The studies found that preferences for toys differ by sex, with boys looking longer at cars and girls at dolls, but preferences for colour do not. So perhaps it's not surprising to learn that back in 1918 the trade publication Earnshaw's Infants' Department wrote that babies' clothes should be pink for a boy and blue for a girl. **SB**

What's the longest an animal can survive without oxygen?

A Many species of bacteria and protozoa don't need oxygen at all, and in 2010 researchers also found three new species of microscopic multicellular animals that can survive without oxygen, living in the seabed mud of the Mediterranean Sea.

All vertebrates need at least some oxygen, but the record for holding their breath goes to the endangered desert pupfish Cyprinodon macularius. This 7.6cm fish has evolved to randomly switch its metabolism over to an alternate pathway that doesn't use oxygen and produces ethanol as a byproduct. They can survive like this for up to five hours at a stretch. **LV**

The desert pupfish is restricted to just a few sites in the US and Mexico

Why do live events transmit faster to my digital radio than my TV?

A Digital audio or video is transmitted as a series of binary bits. Like a dam holding back water in a stream, broadcast equipment stores up a backlog of data. Then, if there are dropouts in transmission, there's a sufficient supply to maintain the signal without interruption. Some services buffer more than others, explaining the discrepancy between digital radio and digital TV. **GM**

PHOTO: GETTY X2

Evolving Ourselves:

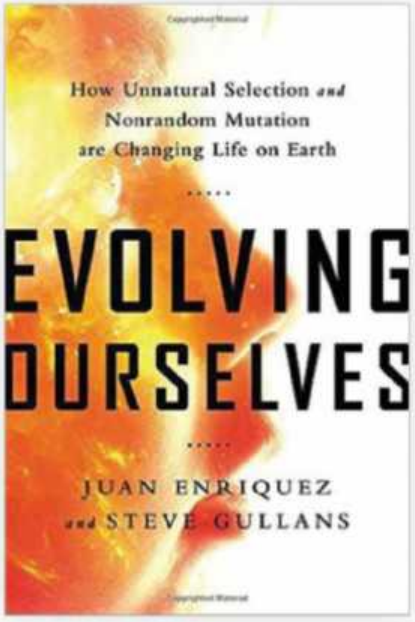
Juan Enriquez and Steve Gullans
Oneworld P

Are humans still evolving? Given our ingenuity and the myriad ways we've found to outwit the whittling force of natural selection, it can sometimes feel like the answer is 'no'. But, according to future-thinking venture capitalists Juan Enriquez and Steve Gullans, human evolution is not just still occurring: it's taking place faster than ever before, and we're the reason why.

"Over the past century, as our species grew by billions, concentrated in cities, smartened, and domesticated itself and its surroundings, we became the fundamental driver of what lives and dies," they write. Through this 'unnatural selection', Enriquez and Gullans claim that we've ended up evolving ourselves.

We have certainly changed a lot. Over several enthralling chapters, the authors illustrate the dramatic extent of our power to transform. An area equivalent to the whole of South America is under cultivation to provide food for ourselves and our animals. We are in the midst of an autism epidemic. Allergies are flaring up as never before. Global obesity is ballooning, fed by "tidal waves of nachos and pizza". We are moving into cities. "It would be surprising if such massive changes did not lead to rapid adaptation and ultimately speciation," they write.

"Evolution is not just still occurring: it's taking place faster than ever before, and we're the reason why"



In addition to unnatural selection, Enriquez and Gullans suggest another force that's driving human evolution. Our ability to create 'non-random mutations', tinkering with the very material of inheritance, must be taking the human genome in a new direction, they assert.

The authors entertain some wacky but plausible future scenarios, predicting that we'll soon be editing our genomes and wiring up our brains to computers. They also veer into the realm of science fiction, anticipating a world in which we'll be cloning ourselves and transplanting emotions, memory and consciousness into these brave new brains.

All of this makes for fascinating reading, but Enriquez and Gullans seem to be living in some kind of magic scientific bubble, free from the messy influence of the rest of human society. Sure, we are changing ourselves and our planet in terrifying, fabulous ways. But change is a far cry from adaptation and speciation. Only time (and a dose of good old Darwinian natural selection) will tell whether any of this 'unnatural selection' or 'non-random mutation' amounts to anything approximating evolution at all.

HENRY NICHOLLS is a freelance science writer and BBC radio presenter

H Hardback P Paperback

MEET THE AUTHOR

Steve Gullans

What do you mean by the term 'unnatural selection'?
We use this term simply as a contrast to the natural world, to describe the human-created changes that now dominate the planet.

Where do we see this happening?
The animals and plants that survive in cities did not exist in their current state in Darwin's time. Our pets would not survive in the savannahs of Africa – we've created many breeds that are not part of the natural world. In humans, we've seen increases in intelligence, height and other traits over the past 50 years. Darwin's theory is generally applied over long periods of time, but scientists are finding that evolutionary change can occur quickly, over a few generations.

What's the most remarkable way in which humans are changing?
I think it's the way our diets have changed today compared to 150 years ago. We now know that the microbes in our gut are very responsive to the food we eat, which is nothing like the primitive food that our bodies learnt to accommodate. These bacteria make hormones and vitamins for our hearts and brains, and studies show that what you eat is having a much longer-term impact than you appreciate, being passed on to your children through signatures in your DNA.

Do you think humans will eventually evolve into separate species?
We already see people break up into different social structures. So when changing a trait is as easy as getting a tattoo, you will find people who will experiment. We might not call it a new species, but self-segregation of people with different traits is inevitable given the technologies we're looking at in the future.

Thing Explainer: Complicated Stuff In Simple Words

Randall Munroe
John Murray

Stuff in the Earth we can burn (oil), big tiny thing hitter (Large Hadron Collider), and bags of water you are made of (cells), are some of the things Randall Munroe explains with blueprints and 1,000 of the most common English words.

Munroe once worked for NASA and now draws cartoons for the website xkcd. He admits to spending a lifetime worrying about sounding stupid. Using big words has helped him feel better. In this book, he wanted to write about 'cool ideas in new ways', without using big words.

To explain biological cells, Munroe uses a smart picture with parts dumbly labelled 'strange boxes', 'bags of death water', 'empty pockets', 'things that make you sick' etc. Such contrived simplicity fails to tell us the function of cells as tiny chemical factories. A chart called 'the pieces everything is made of' is the Periodic Table. Explaining 118 elements in terms of 'metal we add to other metals', 'rock that makes glass blue', 'the stuff teeth are made of' is certainly new. It is not cool.

If science is not your bag, Thing Explainer can mislead you and make you feel stupid. If it is, the book might make you feel cross. Nice idea. Smart pictures. Dumb words.

■■■■■

CHRISTINE EVANS-PUGHE is a freelance science and technology journalist

Hamburgers In Paradise: The Stories Behind The Food We Eat

Louise O Fresco
Princeton University Press

"The hamburgerization of the world is a fact," states Louise Fresco. According to Fresco, the hamburger symbolises a global aspiration for a "Western, free, and carefree way of life". It also represents the dangers of excess and the shift to high consumption of animal proteins. Hamburgers In Paradise covers topics from sustainable food production to biotechnology. Fresco sets out a 'Paradise Theory' to explain why we have a complex relationship with food, seeking abundance yet longing for a lost 'idyllic' way of life.

I was interested to learn that as an occasional meat-eater I am a 'flexitarian'. I then felt quite smug, as Fresco calls for a reduction in meat consumption, driven by concerns for the environment, animal welfare and public health.

Fresco's ideas are interesting, yet her verbose text can be frustrating. One particular phrase jumps out: "The words 'Dinner's ready' denote a state of mind determined by the topography of the table". Put simply, where you sit in relation to your dining companions affects your social interactions. While the full text may prove indigestible, this book has plenty of nuggets to nibble on.

■■■■■

EMMA DAVIES is a freelance writer with a background in chemistry and food science

Atmosphere Of Hope: Searching For Solution To The Climate Crisis

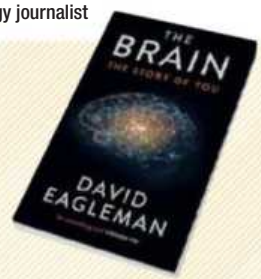
Tim Flannery
Penguin

Science writers don't come much better than Tim Flannery. After The Weather Makers, his lucid study of climate change published a decade ago, Richard Branson asked him to help judge a $25m award to find a way of removing a billion tonnes of carbon dioxide (CO_2) from the atmosphere. Nobody has won yet, but the ambitions of the 11 finalists form the heart of this dose of climate optimism.

Giant air conditioners, powered by wind, could turn the atmosphere's CO_2 into dry ice over the frozen wastes of Antarctica. Or we could give nature a helping hand by creating seaweed forests across the world's oceans. The holy grail might be combining wood-burning power stations with chemical capture of their emissions. Provided you plant new trees, the result would be an energy industry that generates electricity by sucking CO_2 out of the air. Such ideas may sound mad. But Flannery says they "have fundamentally altered my perception about how we might respond to the climate crisis". The tools to avoid climate disaster exist, he says. "We can do it."

■■■■■

FRED PEARCE is a science writer whose latest book is The New Wild



The Brain: The Story Of You

David Eagleman
Canongate

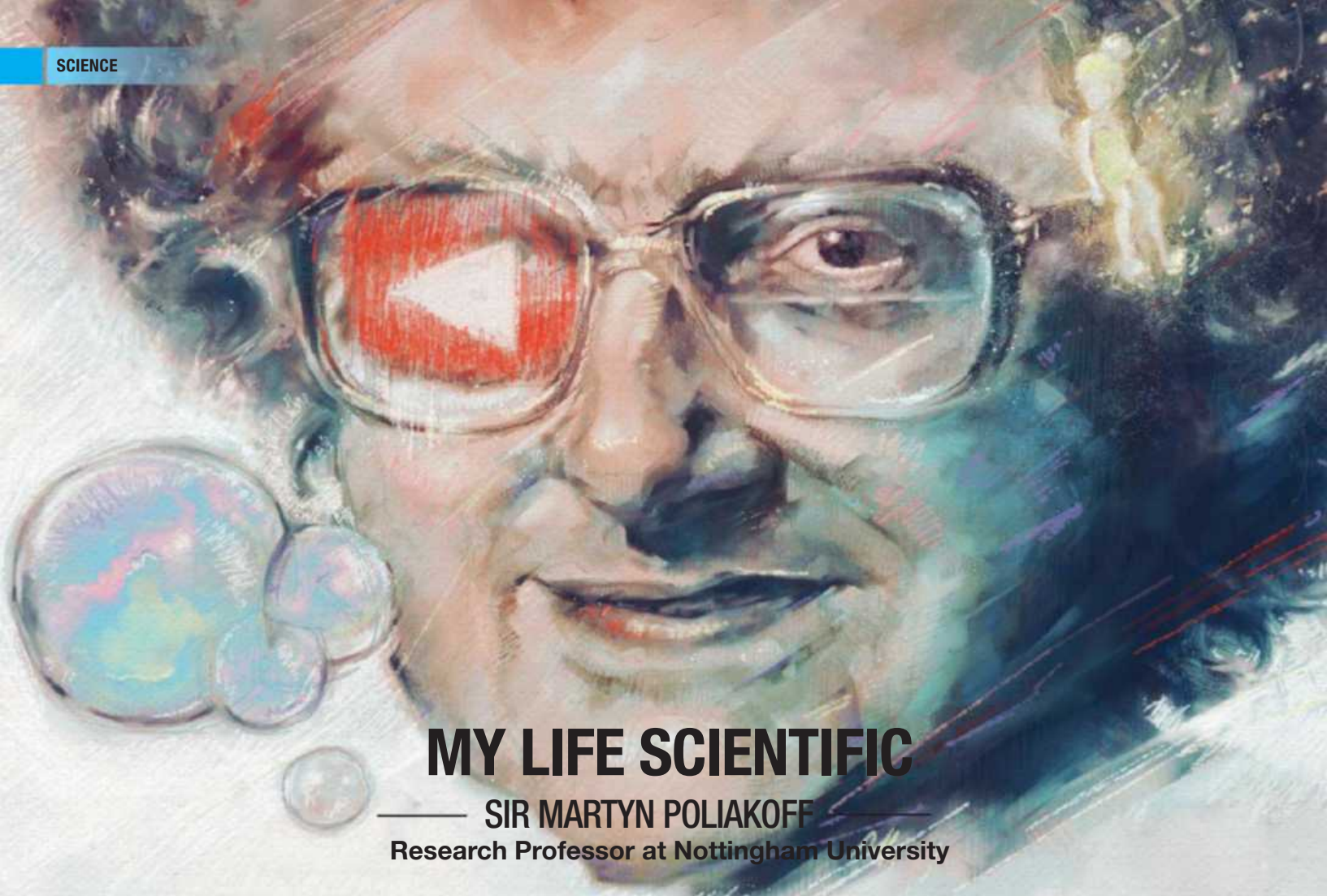
David eagleman's book The Brain: The Story Of You is an informed, digestible travelogue about the territory between brain and mind. Neuroscientist Eagleman covers the ground efficiently – how the brain is 'wired' to further our chances of survival; how baby brains develop and teenage ones erupt; the weird quirks of human memory and the strange processes that underlie the apparently simple act of perception. He visits consciousness and raises (then ducks) the thorny question of free will, then strides on to cover the social brain, empathy and a possible future in which the mind blends seamlessly with digital technology.

Eagleman outlines fascinating stories and studies. There is the experience of Mike, for example, who gained sight after 40 years of blindness, but still prefers to ski blind.

There is something disappointing about this book, though. Eagleman has a rare ability to combine science with literary panache, but you don't see much of that talent here. If you want Eagleman at his best, then pick up a copy of Sum – his brilliant collection of short stories.

■■■■■

RITA CARTER is a lecturer, writer and broadcaster who specialises in the brain



MY LIFE SCIENTIFIC

SIR MARTYN POLIAKOFF

Research Professor at Nottingham University

My grandfather invented the volume control you get on radios as well as the he induction loop that is still used in theatres to help people with hearing difficulties. My father was a physicist too. Even when I was young, he had already decided that I would follow in his footsteps and become a scientist.

I've always worked obsessively. My parents went to my school to complain that I was working too much. But the teachers just laughed and said they wished this problem was more common.

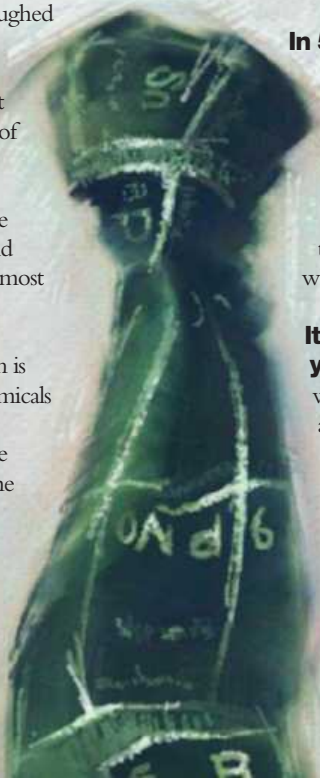
I have two jobs at the moment. I'm Research Professor at Nottingham University, and Foreign Secretary and Vice President of the Royal Society – each of them takes 60 per cent of my time!

Sadly, I have little spare time for hobbies. But I do like reading: biographies and history mainly. My father was Russian, and although I'm not a native speaker, I do try to speak some Russian most days.

Research is almost an addiction. The planet's population is growing. We have to find cleaner, greener ways of making the chemicals that we need. I'm particularly interested in how to make reactors where light is used to drive chemical reactions with less waste. One reactor is based on an idea I had while I was in the bath. One of the nice things about being a scientist is that you discover new things which excite you.

I look a bit like Einstein. There's a portrait of him when he was young in the Dining Room at the Royal Society. When I show it to people, I tell them that it's a portrait of Einstein before he looked like me!

The Periodic Table of Videos is an extraordinary project. We've made 570 YouTube videos that have attracted millions of hits. I get emails almost daily from fans across the world and I often get recognised when I'm out and about.



In 50 years or so, one-third of the world's population will be living in Africa. They will face huge problems with soil erosion, water shortages and feeding the growing population. One has to have faith that science will overcome these problems. So I'm very keen to promote science in Africa. African countries need to have their own research scientists on the front line from where they can mobilise the international community.

It's a real privilege to work with so many young people. It's rather like Peter Pan. My co-workers come and go, but they always stay a similar age. I think that helps me to stay young.

I supplied a few lines of dialogue for my brother Stephen's play. It's called Blinded By The Sun, and was performed at the National Theatre in 1996. I was the only person in audience who laughed at the word 'hexafluoro-isopropanol'. ■

ILLUSTRATION: PAUL TYSALL

Time Out

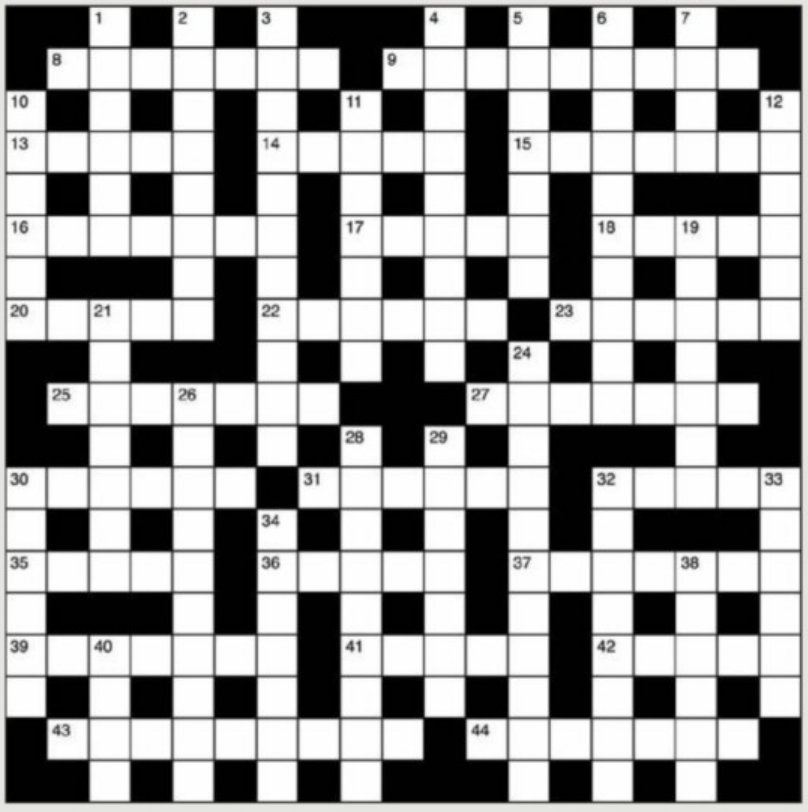
Crossword No.185

ACROSS

8 Firm wind on a bunch of petals (7)
9 Bishop takes iodine, only to beat cyclic pattern (9)
13 America has time for employment (5)
14 Doctor has car fitted with lens (5)
15 Boast at pub of means of entry (7)
16 Viewer has to run to find fastening (7)
17 Cries audibly for some material (5)
18 Home has a creepy sound (5)
20 Proportion of auction gets cancelled, initially (5)
22 Cat has a right to an air passage (6)
23 Masseter, say, gives strength (6)
25 Garnets displaying type of quark (7)
27 Element involved in scare (7)
30 Nose with hesitation to find tree (6)
31 Graduate has advantage of a monkey (6)
32 Something valuable, as arranged (5)
35 Art is performed for part of the flight (5)
36 Laugh about desire for predator (5)
37 Very many directions put me off first (7)
39 Old key turned into part of crystal (7)
41 A rota devised for vital supplier (5)
42 Fish in the corner (5)
43 To me, lager can be used as a sensitivity gauge (9)
44 Allspice to top mine off (7)

DOWN

1 After party, wise man has some pills (6)
2 Dullard hears total scientific opening (8)
3 To my logical reckoning, it's a study (11)
4 I contain a form of plant (9)
5 Fellow has framework of ferns (7)
6 Upset, honey, at forming part of a triangle (10)
7 Fish around the centre (4)
10 Force to take turn in gown (6)
11 Salad ingredient can be a shipping hazard (7)
12 Reporting cheeses, that's easy (6)
19 Cries OK about range (7)
21 I can't change one to a sea anemone (7)
24 Ran curtains off with an atomic number greater than 92 (11)
26 Bear hybrid has share of abnormality (10)
28 Race leader has a cardiac device (9)
29 Arc travelled in European sailing vessel (7)
30 Nut points to money first (6)
32 Article about the lab takes pressure from every character (8)
33 Intellect without second fiddle (6)
34 Having lost weight, being solvent (7)
38 Rowers reach hard part (6)
40 Temperature that can be caught (4)



SOLUTION TO CROSSWORD 182

The Last Word

Scientists can sometimes be pretty unforgiving of mistakes

The Royal Institution (RI) Christmas Lectures are a fine tradition, right up there with carol concerts and eating too much turkey. But one has always stuck in my memory, and to my amazement it's turned up on the RI's online video archive.

That's not because of its age – though it is over 40 years old – but because it caused the RI huge embarrassment. I still remember being dumbstruck by what Prof Eric Laithwaite demonstrated before his wide-eyed audience of youngsters. In classic Christmas Lecture style, he set up various experiments to illustrate scientific phenomena. His aim wasn't to bore on about some esoteric concept, but to show there was something fundamentally wrong with Newton's laws of motion.

The experiments involved gyroscopes, and Laithwaite showed how these spinning contraptions refused to follow expectation. In some cases, they even appeared to turn into antigravity machines.

The professor hailed the strange powers of gyroscopes, and his audience applauded. But then it all got nasty. Despite his international reputation – he helped pioneer maglev propulsion for trains – Laithwaite found himself shunned by the academic establishment. He was accused of the sin of venturing outside his own field and claiming he knew better than experts in theoretical mechanics. Worse, he'd declared he'd spotted something of huge importance they'd all missed, and that one day it would spark a revolution.

Even experienced physicists can struggle to figure out how a bike remains stable

"When Laithwaite died, his ill-judged foray into science popularisation had overshadowed his entire career"

Then it emerged that Laithwaite was plain wrong. Gyroscopes don't violate Newton's laws of motion – as he himself admitted 20 years later (ironically, as part of a BBC documentary about scientific heretics).

But it was far too late. When he died in 1997, his ill-judged foray into science popularisation had overshadowed his entire career. Even the RI refused to publish the transcripts of his Christmas Lectures – allegedly the first and only time that sanction has been used.

Happily, the RI has now seen fit to put the offending lectures online. Anyone who watches the fourth in the series cannot help but be astounded by what gyroscopes can do.

While Laithwaite may have been wrong about gyroscopes, they do demonstrate a truth that can't be repeated often enough: that even school-level laws of physics can throw up extraordinary phenomena. Perhaps the most famous example is flight. Clearly, heavier-than-air planes do fly, and do so in accordance with the laws of physics. The relevant ones are summed up in the so-called Navier-Stokes equations. The trouble is that – contrary to what many textbooks claim – there's no simple explanation for what these hideously complex formulas say about how planes fly.

I recently came across a more familiar example of this phenomenon: the stability of bicycles. Many people think bikes owe their stability to the gyroscopic effect of the wheels. Yet theory and experiment show that's a minor influence. More important is the so-called 'trail effect', generated by the front forks pointing ahead of where the wheel touches the ground.

Yet a team at the Delft University of Technology recently built a bike that's stable without either gyroscopic or trail effects. It works, but no-one can explain why except via some very complex mathematics.

It has been said that no-one understands quantum theory. Therefore, Laithwaite's notorious Christmas lectures should be celebrated for showing that even 'everyday' phenomena can defy simple explanation too. ■

ROBERT MATTHEWS is Visiting Reader in Science at Aston University, Birmingham

ILLUSTRATOR: DEM ILLUSTRATION

tvhighlights

WILD JAPAN

Premieres 8th February. Mondays at 7.05pm (JKT/BKK), 8.05pm (SIN/HK/MAL/TW)
Japan - we think of it as a crowded, manicured, highly industrialised archipelago. But Japan has a surprisingly vast range of landscapes, from the far north, where sea eagles walk on frozen waters, to subtropical southern islands, with coral reefs and mangroves, and the central islands, with forested mountains, home to bears and monkeys.

ARE HEALTH TESTS REALLY A GOOD IDEA?

Premieres 5th February. Fridays at 9.45pm (JKT/BKK), 10.45pm (SIN/HK/MAL/TW)
Are expensive scans worth it? What about DNA testing for diseases? In this surprising and insightful film Michael Mosley investigates the real value of health tests.

OPERATION MANEATER

Premieres 11th February. Thursdays at 8.50pm (JKT/BKK), 9.50pm (SIN/HK/MAL/TW)
Mark Evans explores the latest attempts to protect humans and deadly predators from each other.

TRUST ME, I'M A DOCTOR SERIES 3

Premieres 26th February. Fridays at 9.45pm (JKT/BKK), 10.45pm (SIN/HK/MAL/TW)
Michael Mosley and his team of doctors return to tackle more questions about our health, offering uncomplicated, trustworthy advice on important and topical medical issues.

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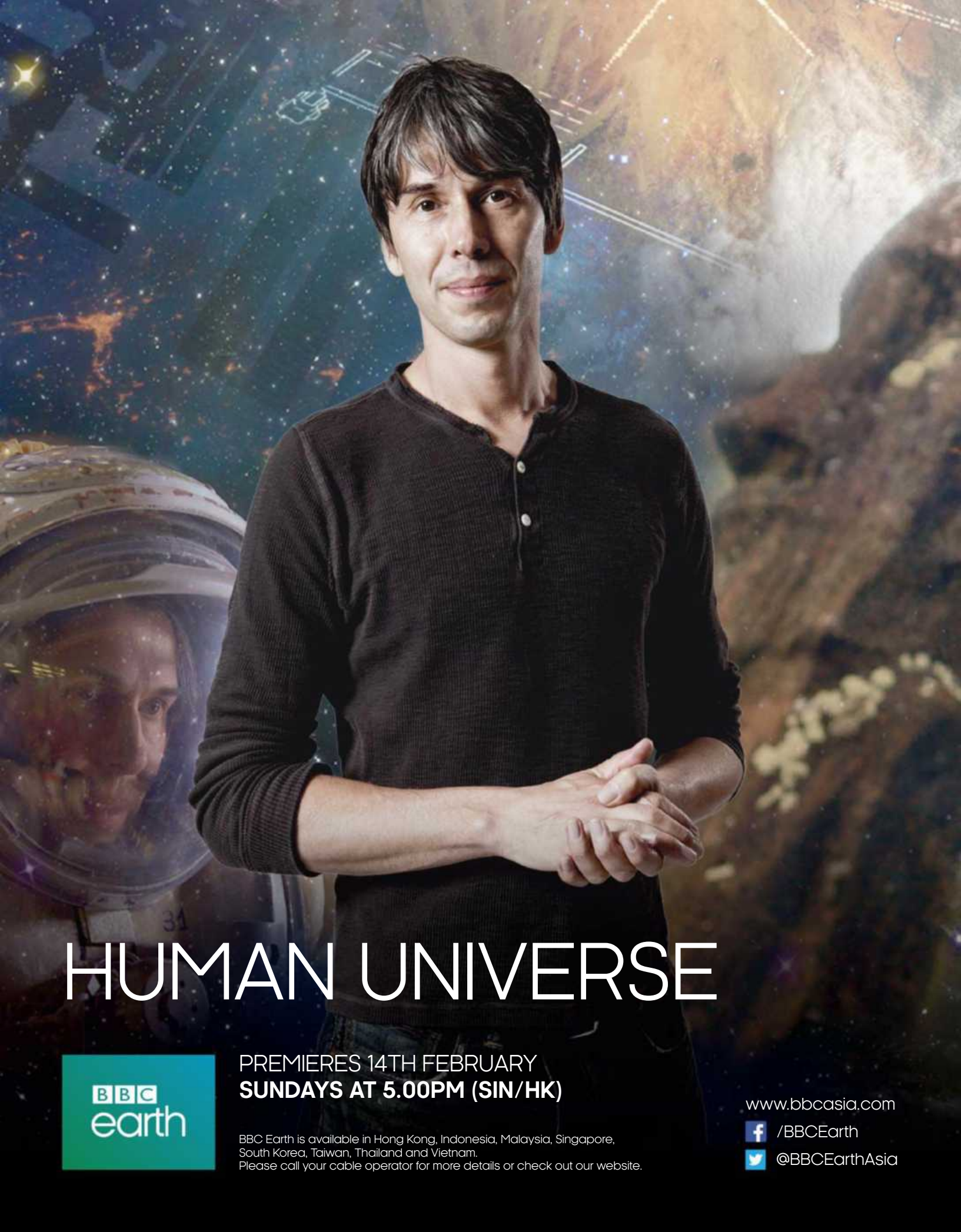

BBC earth

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